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Improving the Order-Picking Process in the Case Company

Helsinki Metropolia University of Applied Sciences

Master's Degree

Logistics Management

Master's Thesis

29 October 2018

What an impressive journey! Year 2018 has been hectic. New challenges flooded into my work and study, as well as my family. I am so busy, just like restless ants on a hot pan, and feel deeply that time is so limited and precious. Although quite challenging and super intensive, this study was really educational and rewarding. Without receiving helps and supports from many people along the way, I believe that this trip would be even harder and longer. Thus, I would like to take this opportunity to thank everyone who offered their helping hand to me.

First of all, I would like to express heartfelt thanks to my instructor, Dr. James Collins, who provided me with professional guidance throughout this study. I am really impressed by his simple but logical thinking, such as differentiating between 'complex' and 'complicated'. He was always patient and warm-hearted to help me. Honestly, without his professional guidance, this paper could not be accomplished timely.

I also would like to thank the other instructor, Dr. Zinaida Gravovskaia, who helped me regain confidence and gave me a lift from plenty of challenges along the whole degree programme. From the courses assignments to thesis writing, from individual studying to team presentation and site visits, she was always keeping company with us and give any necessary help. I really admire her professional ethics and positive attitude, as well as selfless contribution. These moral characters are my pursuing target in life.

In addition, I want to thank the case company for giving me this opportunity to conduct the project. Especially, I want to thank Juha Stenman, the Warehouse Manager of the case company, for providing this interesting and meaningful topic and all needed support along the study. Furthermore, I want to thank all informants who shared their professional knowledge and support during this study.

Finally, I want to thank my family, especially my wife. Without your support and help, I would never achieve this point. You know what we have experienced, and we will together head for new horizons in future with our son, and everything will turn well!

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October 29, 2018

Author Title	Bin Gao Improving order picking process in the case company
Number of Pages Date	74 pages + 3 appendices
Degree	Master of Engineering
Degree Programme	Logistics Management
Instructors	Dr. James Collins, Senior Lecturer Zinaida Grabovskaia, PhL, Senior Lecturer, Head of Program Juha Stenman, Warehouse Manager
<p>This paper focuses on improving the manual order-picking process in the case company warehouse. Order picking process has long been identified as the most labor-intensive and costly activity (up to 55% of the total operating expense) for most warehouses, so as in the case warehouse. In order to operate efficiently, the order picking process needs to be robustly designed and optimally controlled.</p> <p>Action research is selected as a research approach for conducting this study, which involved diagnosing, planning, taking action and evaluating activities and was a cyclical process. Furthermore, three rounds of data, including qualitative and quantitative data, were collected and analyzed using various methods to provide adequate and solid foundation.</p> <p>The study is designed into 4 key steps. It starts from the current state analysis to find out the weaknesses and strengths of the order-picking process in the case company, based on the first round of data collection (Data 1). Then, combining with the outcomes of the current state analysis, this study moves to establish a conceptual framework using existing knowledge and available best practice. Thereafter, on the basis of the outcomes of the conceptual framework and the current state analysis, as well as Data 2, the initial proposal is formed and tested in the real workplace. Finally, the proposal is validated and finalized on the grounds of Data 3.</p> <p>The paper shows that substantial improvements in the case company warehouse can be achieved by applying a tailored solution. Comparing to the performance of 2017, the picking productivity increased from 31.33 lines/ (labor hour) to 43.12 lines/ (labor hour), improved around 37.6%, by application of visualization management. As for reduction of travel distance, approximately 10% extra improvements could be achieved by partially applying re-slot fast moving area and zone picking. According to the rough calculation, around 2-4 pickers can be saved, comparing to the performance of 2017.</p> <p>Finally, the validated proposal can also have a significant effect on the whole warehouse management and supply chain management, thus going beyond the order-picking process itself. It gives more granular knowledge to the organization and managers could better forecast the amount of work and labor cost before several months. Thus, the analysis and the proposed solution give contribution to improving the overall performance of the case company.</p>	
Keywords	Order picking process, action research, unproductive travelling, performance measurement, visualization management, zoning

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1 Introduction

Nowadays, the global economy is moving dramatically from product-oriented to service-oriented. Thus, those who could offer better services to meet their customers' needs, have a promising future. Logistics plays an important role in today's fast moving and service-oriented economy, especially distribution center and warehouse. In distribution centers and warehouses, longer order throughput times is a constant pressure for most cases, extremely longer order-picking time. In most activities of typical warehouses, the order-picking has been identified as the most labor intensive and costly activity, accounting for around 55% of the total operating cost of a warehouse. Improving the order-picking productivity is a common and urgent question for most warehouses and has been paid more attentions by cooperate managers and researchers in this field.

There are plenty of researches talking about order-picking issues. New models and new problems have been studies during last two decades. However, there is still a lack of standard way to settle it. Mostly it varies case by case. This calls for researchers to investigate more cases and studies on this topic and spend more energy on addressing order-picking productivity.

1.1 Business Context

The case company is a spare parts wholesaler and a repair business. It was found in 1930, owned by a Finnish family and has more than 87 years professional experience in automotive service field. It is one of the largest automotive service companies in the Baltic Sea region and employs more than 500 people in Finland, Sweden, Latvia and Estonia. The headquarter of the case company is located in Espoo, Finland. In 2016, its turnover achieved up to EUR 113 million. The company aims to become the leading provider of automotive services in Northern Europe.

The warehouse of the case company is a traditional warehouse. Similar as other typical warehouse, order-picking is the biggest labor-intensive and costly activity in this warehouse, followed by shelving activity. Packing and shipping are operated in two areas. Most of activities are operated manually and part of them are applied semi-automation system, such as zone AUTO. This warehouse starts to work at 7 am. and off work at 11 pm (two shelves) during working days and works on two shifts. Most workers

of this warehouse are rented from a third party, such as Transval Oy, in order to save labor costs as well as keeping flexibility.

There are plenty of car services stores located in different cities of Finland, such as Helsinki, Oulu, etc. The case warehouse is working as a distribution center in Finland to support different downstream services stores. Basically, delivery service is offered by two ways: For capital area, the case company uses own car to delivery products to their customers and partners; For other regions, several logistics companies are selected to delivery products.

1.2 Business Challenge, Objective and Outcome

There are several reasons to conduct this thesis project. The first and major one is the need to improve the order-picking activity, which is the most labor-intensive and costly part for the case warehouse, accounting for up to 55% of the total operating cost, same as other typical warehouses. This has become a growing problem of the case warehouse in daily operations. The case company plans to improve picking productivity and calls for analysis and recommendations before decision making. To help and improve productivity, in 2017, the case company planned to introduce a new warehouse management system (WMS), called enterprise resource planning (ERP) to replace the current operating system. The warehouse manager team realizes that it is urgent and a great opportunity to make the knowledge of warehouse granulation and prepare well for the operation system update. Therefore, the case company has become interested to identify the current weaknesses and eliminate them before implementing the new system.

Furthermore, the pickers also face some repeated problems when picking. Currently, the picking process is introduced very briefly, by word of mouth of the warehouse managers when new workers come to the workplace at the first day. But, in reality, the training time is extremely short, and the process is implemented case by case, due to the lack of official manual and enough professional training. Thus, it is urgent to establish an official picking process and document it for future training and further analysis.

Accordingly, the primary objective of this thesis is *to propose improvements of the order-picking process of the case company*. Plenty of picking methods, warehouse design and advanced technologies exist in the literature, however, there are still considerable difficulties in applying these tools to realistic situations, one of biggest issue is cost.

Improving the current order-picking process with limited budget is a challengeable and interesting topic.

The outcome of this thesis is an improvement proposal for the order-picking process. Order-picking process affects significantly the order cycle time. If the order-picking process flows fluently, the whole order cycle time could reduce significantly, so as to more customers get satisfied and more potential orders involved.

1.3 Thesis Outline

This thesis is conducted based on the Finnish logistics context and spare parts warehouse, specifically for the case warehouse, and discusses mainly the order-picking process, which includes a period from warehouse receiving order tasks to pickers releasing products to packing area.

This thesis starts from the business challenges of the case company, and then analyzes the current picking performance and sorts out the bottleneck of picking process. Supported by tailored theory and best practice, it provides corresponding solutions to eliminate the weakness and improves picking productivity of the case company. Furthermore, the study gives the managers and workers of the case company more specific and granular knowledge of their warehouse. One super important highlight of this thesis is that the case company only need to invest limited capital to achieve long-term benefits.

The study is organized in seven sections. Section 1 gives an introduction of this thesis, mainly focusing on the business challenge, objective and outcome. Section 2 explains research approach and methods, and research design, along with data collection and analysis. Section 3 focuses on the current state analysis, supported by internal documents and a first round of data collection (Data 1). Based on the findings of the section three, Section 4 depicts establishing conceptual framework of selected elements. Section 5 describes establishment of the initial proposal by combining a second round of data collection (Data 2) with key findings of section four. Section 6 is about validation of initial proposal using a third round of data collection (Data 3) and the last section discusses proposals for next steps and draw out the conclusion of this thesis. In addition, the evaluation of this study is explained.

2 Method and Material

After identifying the objective, this section gives an overview of the methodology applied in this study. It includes the research approach and methods, research design as well as data collection and analysis method.

2.1 Research Approach and Methods

Selecting a proper research strategy and approach is a prerequisite of a successful research. Research is defined as “a scientific and systematic search for pertinent information on a specific topic.” (Kothari 2004). According to Dudovsky (2018), the basic types of research mainly include following two categories: applied vs. fundamental research. Applied research is to suggest remedial solution for an immediate problem facing a society or an industrial/business organization, while fundamental research mainly focuses on generalizing and formulating a theory (Kothari 2008; Bhattacharyya 2006; Bajpai 2011; Dudovskiy 2018)

For applied research, research strategy includes quantitative vs. qualitative strategy (Kothari 2008). Quantitative strategy basically refers to generate data in quantitative form which requests rigorous quantitative analysis in a rigid and formal way. It is often based on the quantitative measurements of some characteristics, such as key performance indicator (KPI), and used to make statistical comparisons, statistical inferences or test theoretical propositions. Qualitative strategy, on the other hand, is used for little known phenomena or innovative systems. It is often capable for field studies where variables are many, or have not yet been identified, or difficult to identify. It is also used when case is special (such as, too big or irregular) or cases cannot be done experimentally for some reason. The common methods of qualitative research are observations, interviews, participation and document reviews. Sometimes, mixed of qualitative and quantitative strategy is used when doing research, because it is very hard to draw a line between them. (Kothari 2008; Dudovskiy 2018; Damien 2007; AbuSabha & Woelfel 2003; Rebecca et al. 2013; Srnka & Koeasegi 2007)

This research mainly uses qualitative research with some elements of quantitative analysis. It starts from the real business challenge of the case company, and the purpose of this research is to address a practical problem. During this study, various research methods and internal documents are applied, such as face to face interviews, workshops

and observation. For example, in current state analysis and building initial proposal parts, quantitative calculation of internal picking data is used, while interviews and workshops are used when mapping down the current picking process and the warehouse layout.

As for research approach, this research adopts action research (AR) to conduct the study. According to the statement of Coghlan & Brannick (2005), action research is a deliberate, cyclical process of diagnosing, planning, taking action and evaluating (shown in Figure 1). In addition, it is combined research and practical action where the researcher joins with and acts with practitioners to help improve theory building and organizations and communities. (Nielsen 2014). Action researchers hold a dual role of holding a membership in the organization and conducting research. The researchers collect comprehensive data relevant to specific problem from the case company and the existing knowledge of this topic from a literature study. (Dudovskiy 2018; Kaplan 1998)

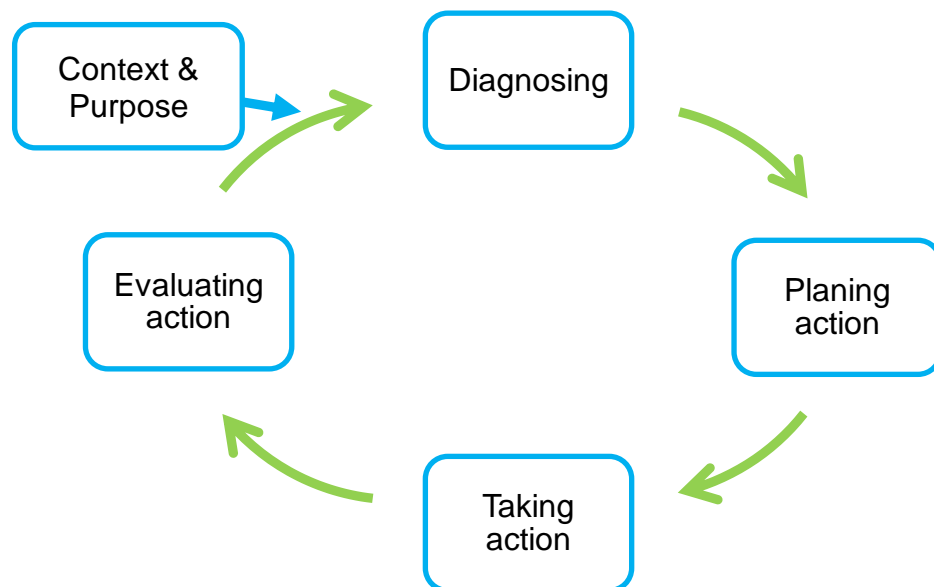


Figure 1. The Action Research cycle.

As shown in Figure 1, act research involves being engaged “in a rigorous series of diagnosing (situations), planning, taking action and evaluation and is a cyclical process.

Action research is applied to solve real organizational problems via integrating existing organizational knowledge with behavioral science knowledge (Coghlan & Brannick 2005; Dudovskiy 2018; Nielsen 2014). Based on interpretations of Reason and Bradbury (2008), action research has big significance in developing practical knowledge to pursue valuable human goals because it is on the basis of participatory worldview. Simultaneously, it requires members in organizations to develop scientific knowledge,

self-help competencies as well as innovation to improve the performance of the organization. (Coghlan & Brannick 2005) Therefore, action research is a combinational method that build inductive and practitioner-based theory to help solve practical problems of organizations. It not only benefits individuals, such as researcher and practitioners, but also the organizations, even the whole world. (Nielsen 2014)

Action research mainly includes the followings steps when addressing an organization's problem: firstly, the research diagnoses the problem of the case organization via gathering various data. And then consult relevant literatures to find existing knowledge and best practice of the problem identified in the front stage. In sequence, the researcher and the stakeholders have an agreement on some proposals, which would be piloted by the organization. Finally, after a fixed time, the researcher analyzes the result of implementation based on agreed measurements to assess the effectiveness of the changes. (Goddard & Melville 2001; Coghlan & Brannick 2005; Dudovski 2018).

To sum up, action research is an interventional activity, including observation as well as a change, plan, act, test activities. Furthermore, it is a reiterative activity, meaning firstly implement a change and then study the effects of this action. It is also done in close collaboration with other people and the result are fed back to the organization. Thus, action research was selected as a suitable method for conducting this study.

2.2 Research Design

This sub-section describes the research design of this study (shown in Figure 2 below). The following steps are conducted based on this objective to make sure the whole project is result-oriented and meaningful.

This research started from, first, setting the objective for the study. The objective came from business challenge and interviews with the key stakeholder of the case company.

Next, the study analyzed the current state of the case company. It started by mapping the current picking process and warehouse layout via self-observation and theme content interviews on the 1st round draft process. Furthermore, another round theme content interview was conducted in order to find out the weaknesses and strengths of the current picking process. In addition, it also included a quantitative analysis of the current picking performance using historical order picking data. Finally, a workshop was conducted in order to select the focus area for improvement in this thesis.

The research design is shown in Figure 2 below and consists of five consecutive steps.

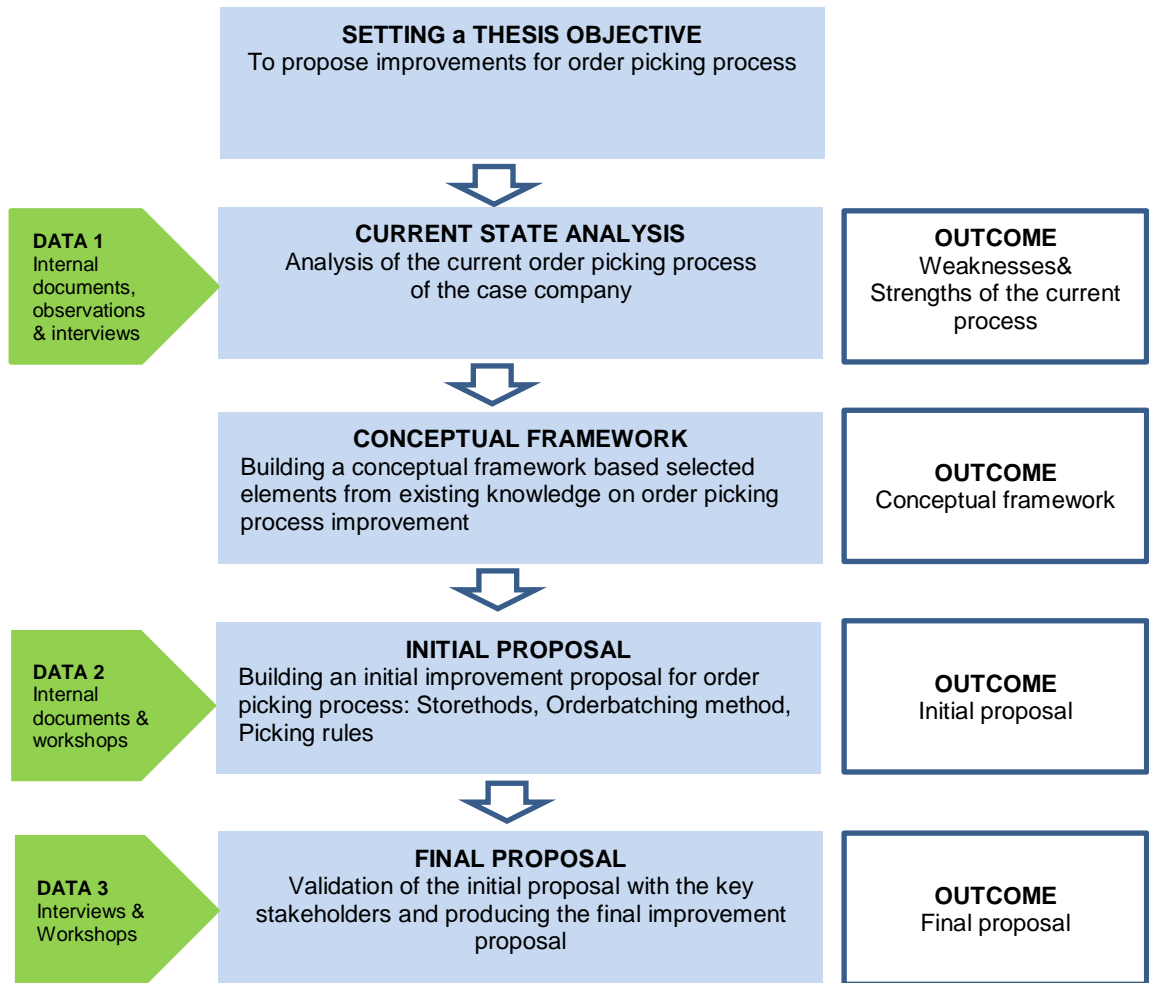


Figure 2. Research design of this study.

As showing in Figure 2, as a result of the current state analysis, after serious discussions with key stakeholders, some key elements were selected as the focus for improvement. The outcome of the current state analysis was the list of weaknesses and strengths in the current order picking process and the current picking performance of the case company, as well as selected areas for improvement.

The following step established a conceptual framework using existing knowledge and available best practice in this field. In this part, each of selected elements was studied via consulting plenty of relevant literature and best practice. Furthermore, some useful tools and practical methods were identified to support improvement actions. The

outcome was a conceptual framework that summarized most useful tools and suitable theory for addressing the selected weaknesses.

In the next step, the aim was to build an initial proposal for improving the order picking process. During this stage, the author re-visited some key stakeholders to discuss the initial proposal building and collect feedback on the draft proposal, which made Data 2. The initial proposal is a combination of outcome of CSA, the conceptual framework, Data 2 and quantitative analysis of picking performance.

In the last stage, the initial proposal was tested in the real workplace in a relatively small scale. The tests last two months and are conducted in two steps according to selected area for improvement. Thereafter, the third round of data collection (Data 3) was conducted by running workshops of proposal validation with key stakeholders. After checking the result of test and feedback of key stakeholders, the initial proposal was validated and became the final proposal, which is ready to be fully implemented in the case company.

2.3 Data Collection and Analysis

This subsection depicts data collection and data analysis in this study. This study draws from a variety of data sources (including quantitative and qualitative data) and consists of three rounds of data collection (shown in Table 1). Each stage has a clear outcome, which supported by sufficient data resources, various data collecting methods and reliable data analysis methods.

All interviews were coded by field notes. Summary of interviews, workshops and discussions of Data 1-3, could be found in Appendix 1, 2 and 3.

Table 1. Data Collection in this study.

	CONTENT	SOURCE	INFORMANT	OUTCOME
DATA 1 CURRENT STATE ANALYSIS	-Description of the current picking process -Summary of weakness and strengths	-Theme interviews -Observation -Workshop -Work schedule	-Warehouse Manager -Picking Supervisor -Experienced Pickers (5y+) 2 p	-Summary of strengths & weaknesses -Current picking performance

	-Review of picking performance	-Picking data set of year 2017	-Less Experienced Pickers (3~4y) 2 p -New Pickers (6 m-) 2 p	
DATA 2 BUILDING PROPOSAL	Comments on the initial proposal from key stakeholders	-Interviews -Stakeholder workshops -Picking data set of year 2017 -Picking data set of Aprils 2018	-Warehouse Manager -Picking Supervisor -Experienced Pickers (5y+) 2 p	-Initial proposal of a partially improved picking process
DATA 3 VALIDATION	-Test proposal in real workplace -Feedback of proposal validation	-Result of testing -Stakeholders meeting	-Company decision-makers	-Final proposal of a partially improved picking process

As shown in Table 1, the first round of data collection (Data 1), was conducted in the current state analysis stage. During this round, three different methods of qualitative data collecting (self-observation, theme content interviews and workshop) were applied.

Self-observation was used when mapping the current picking process and drawing warehouse layout. The author spent three afternoons to observe the picking process onsite and drafted the 1st version of picking process of the case warehouse. Drawing the layout took another week of self-observation, along with the help from the warehouse managers.

Theme content interviews were applied in two stages. The first stage was in collecting comments on the 1st version of the picking process. Questions of this interview included: what the current picking process is in the case company; and what the differences and improvements of 1st version of picking process are, comparing to the reality. The author selected 2 experienced pickers (more than 5 years working in the case company), 2 less experienced pickers (3-4 years), 2 new pickers (less than 6 months), picking supervisor who is responsible for picking, packing and shipping, and the warehouse manager as the key informants. The second stage was in identifying weaknesses and strengths on current picking process in the case company. Questions of this round interview included:

what the strengths of the current picking process are; and what the weaknesses of current picking process are. Here, 3 more informants were interviewed. The quantity of informants was 11 out of 18 (the total number of pickers of the case company). According to self-observation and the face-to-face interviews with stakeholders, the current picking process was successfully mapped, which was confirmed by all stakeholders.

In addition, a *workshop* was conducted to discuss the weaknesses and strengths facing the case company, based on theme interviews of stakeholders. Workshop with decision makers was introduced when selecting focus area for improvement from 10 weaknesses.

In terms of quantitative data collection in Data 1, the author received the raw data from the case warehouse management system (WMS) with the help from the warehouse manager, which is picking data of year 2017 of the case company. Based on the elements of statistical analysis, the current picking performance was calculated. The results of all calculation were cross-checked and double-checked by key stakeholders via repetitive work. Data 1 collection took 22 times and more than 1000 minutes interviews.

The second round of data collection, Data 2, happened when build the initial proposal. Again, both qualitative data and quantitative data were involved. Qualitative data came from interviews with key stakeholders in building initial proposal. The author re-visited and interviewed key stakeholders, which included the warehouse manager, the picking supervisor and 2 experienced pickers. Questions of interviews mainly included: what recommendation for reducing unproductive travelling are, what are possible solution for improve pick performance measurement, and what are comments on the draft proposal. Likewise, at this stage the author collected and analyzed the picking data of April 2018 of the case company and the result of calculating was also applied when building initial proposal. Therefore, the initial proposal was formed by combining existing knowledge of literature and key findings of qualitative data analysis, as well as important findings of quantitative analysis. Data 2 collection included 9 times and more than 300 minutes face-to-face interviews.

The third round of data collection, Data 3, came from validating the initial proposal, which also included qualitative and quantitative data. Qualitative data came from theme content interviews and email consult on testing of initial proposal and quantitative data came from testing result and analysis. At the beginning of the validation, partial of initial proposal were piloted step by step in the real workplace. In sequence the results of

testing were analyzed and summarized. Based on the summary of testing, the author interviewed the key stakeholders and checked the performance of new picking methods together with them, as well as collecting Data 3. Through careful test and critical discussion with key stakeholders, at the end, the final proposal was formed, which was ready to be implemented in a larger scale.

In terms of qualitative data analysis, content analysis was applied. Content analysis, as a research method, is extensively applied in qualitative research, such as communication and social research. (Lacy et al. 2015). According to Schreier (2012), content analysis is a systematic and objective way of describing and quantifying phenomena, which is used for analyzing data and interpreting its meaning. By most definition, content analysis meets the standards of a scientific and reliable method. (Srunka & Koeasegi 2007).

As for the quantitative data analysis, elements of statistical analysis were applied. The author firstly collected the original dataset from warehouse management system (WMS) and then analyzed it using elements of statistical methods, which came from the existing knowledge and theoretical literature (discussed in Section 4.2.2). After getting the weaknesses and strengths from qualitative analysis, the author went through them one by one with key stakeholders and collected feedback for further study. Basically, this process rolled up several rounds to get the final result.

The biggest part of data analysis was done in the current state analysis stage, to find out weaknesses and strengths of picking process and the current picking performance of the case company. The second biggest task of data analysis was conducted when building initial proposal. The key findings of them were discussed in Section 3 and Section 5, respectively.

Next section of this paper moves to the current state analysis.

3 Current State Analysis of the Present Order Picking Process

This section discusses the current situation of order-picking activity of the case company. It starts by briefly overview of the current state analysis (CSA), followed by description of the current picking process of the case company by mapping down the current picking flowchart. Thereafter, it moves to identify the weaknesses and strengths based on Data 1 collection. In the following stage, the current picking performance is calculated via historical picking data. Finally, key findings of the current state analysis stage are summarized and selected area for improvement are decided.

3.1 Overview of the Current State Analysis Stage

The main purpose of the current state analysis is to identify the strengths and weaknesses of the current picking process as a basis for improvement.

The first step of CAS is description of the current picking process. In this stage, the author firstly drafts a picking flowchart and warehouse layout of the case company based on self-observation. After that, four groups informants give comments on it, which includes manager group, experienced pickers, less experienced pickers and newcomers. In each group, the author chooses at least 2 representatives to conduct the face to face interviews in order to decrease bias. Combining the comments with the draft process, the author revises the previous version and collects next round feedback from informants. After several rounds of revisions, the final version of the current picking process is formed and confirmed by all informants.

After mapping down the current picking process, the next step is to locate in which part the bottlenecks of this process could be found. To find out the weaknesses and strengths of it, the author conducts the second round of theme content interviews. The main informants are the same as those in the first round, with 3 more informants involved this time and all interviews coded and documented by field notes. After getting sufficient qualitative data, content analysis is applied via three main steps. According to these interviews, 10 key weaknesses and 6 strengths are identified.

After that, the study focuses on the analysis of the current picking performance. Current picking performance is another important element of the current state analysis. In this stage, the author collected the internal documents of the case company, including the raw picking data set of the whole year 2017 and work schedules. From these original

data, the author used elements of statistical method to calculate some key indicators of the current picking performance, such as picking lines per day, picking lines per labor hour, and so on. The quantitative analysis lay a solid foundation for CSA and set a reference object for later validation of initial proposal (Section 6).

The last part of the current state analysis is a summary of key findings as well as selecting areas for improvement. It firstly lists out the key outcomes of each sub-section. And then select two areas as the focus of improvements of order picking process based on extensive discussion with key stakeholders and rigorous analysis.

Next, the content and findings from the current state analysis are presented.

3.2 Description of the Current Picking Process of the Case Company

In the case warehouse, there is presently no official document to describe the current picking process. The case company now has only oral instruction by experienced pickers or managers. Due to this, the author conducts three steps to map down the current picking process, which include 1st version of picking process draft by self-observation, summary of comments of 1st version, and the final version of the current picking process.

3.2.1 1st Version of Picking Process Drafted by Self-observation

The first version of picking process is drafted based on self-observation (shown as Figure 3). As Figure 3 shows, this first version of picking process consists of five key roles, which are customer, seller, picker, packer and sender part. But this study only focuses on the pickers part, which includes activities from orders arriving in warehouse to orders fulfilled and moved to packing part. Other parts are briefly illustrated to keep the completeness of order-fulfillment flowchart.

As shown in Figure 3 below, the yellow box shows customer activities, including ordering (step 1) and receiving orders.

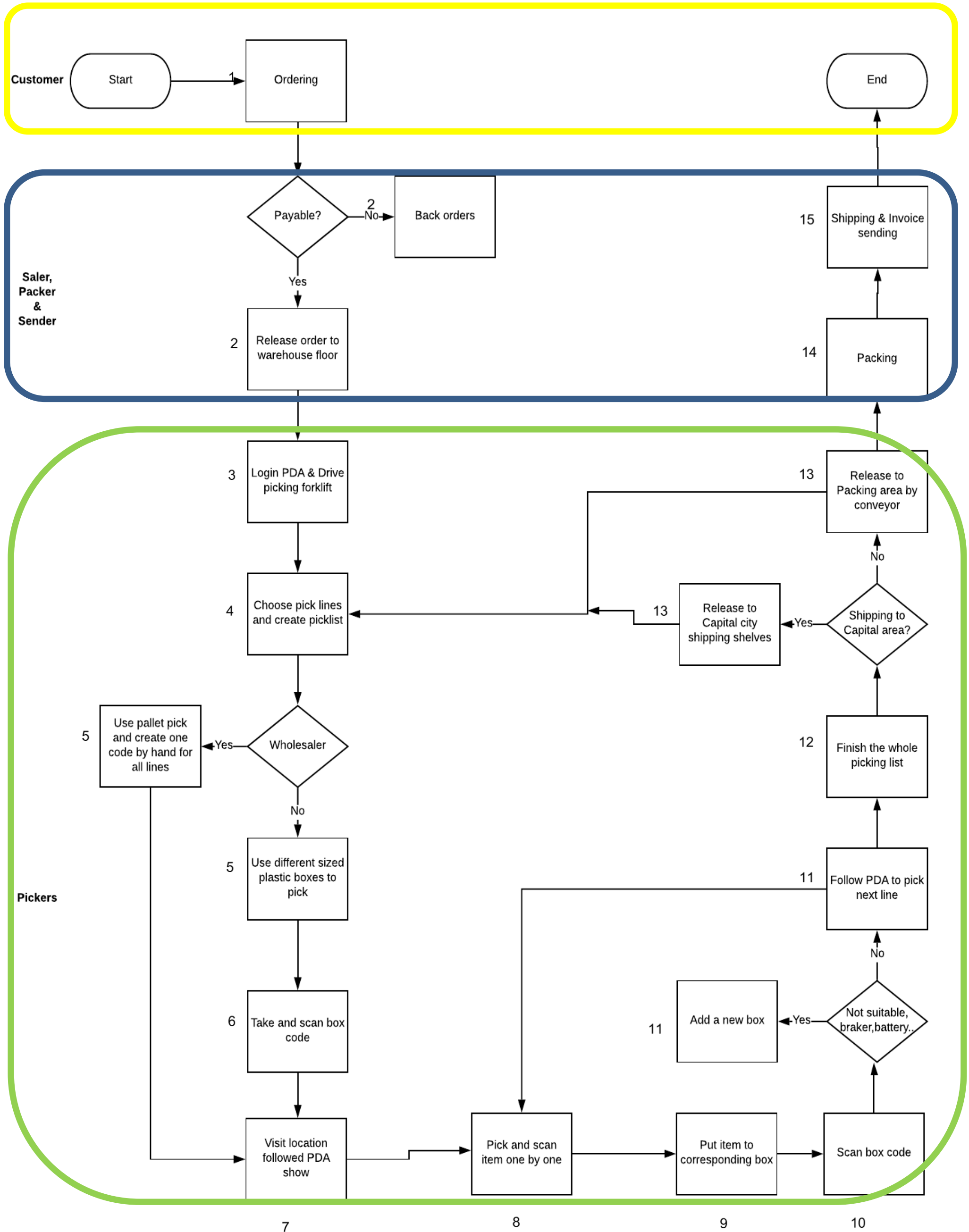


Figure 3. 1st Version of the picking process.

As shown in Figure 3, the blue box shows the basic and main activities of the seller, packer and sender within an order fulfillment process. For the sellers, the main work is to check whether the order is payable (Step 2). If yes, continue the process to send order to warehouse via WMS; If not, save as “back order” for further communication. For the packer, the main job is to sort the picked articles and pack them properly for shipping (Step 14). For sender, there are two main tasks: one is sending the correct products (item and quantity, etc.) to the right customers. The other is sending the invoice to according customers via WMS or email (Step 15).

The green one illustrates the details of the picking process in the case company, which is the focus of this flowchart. As it shows, there are 12 key steps to fulfill an order. It kicks off by “login to a personal digital assistant (PDA)” (Step 3). When login in PDA, different tasks require different resources. For example, if picking task is in zone “AUTO”, pickers must choose AUTO resource to do following operation and each of them has personal account and password for operating.

From Step 4 to Step 7, there is a preparation stage of the order picking. Step 4 is choosing pick lines and create pick list. Picker can select un-picked orders to create a new pick list. Normally, it follows the time windows of orders, which is marked by “priority”. Step 5 is selecting the suitable forklifts and the product mover. Here, there are two options for different orders: for wholesales, use pallets to pick. for others, use plastic box. Accordingly, for a different product mover, there are different kind of forklifts available. An ordinary pick forklift used in the case company could fit 3-4 normal-sized plastics boxes. Step 6 is arranging the selected product mover and scan the box code via PDA. For pallet pick, this step is done by manually and is not written here. Step 7 is following the PDA show to visit locations. In the case company, the pickers follow S-sharp routing to pick items. Generally, it starts from left to right and from high to lower. Some areas adopt zone picking and automatic picking.

Step 8, step 9 and step 10 are specific actions for pick products from shelves in case warehouse. Step 8 is scanning the product one by one. Step 9 is putting items to corresponding box. And Step 10 is scanning the box again to make sure items are in the correct box.

Step 11 is to handle special products, such as heavier products, oils and so on. For special product, it is needed to add a new box to store it and separate it from other products to keep safety. Step 12 is repeating those above picking actions until the whole

picklist is finished. Step 13 is about placing the picked lines to different zones for next operation. One is shipping directly to customers by own car, the other is packing by conveyor and shipping by the third parties.

3.2.2 Summary of Comments on 1st Version of Picking Process

Based on the 1st version of the order picking process, the author conducted interviews with informants to collect feedback on it and revise it (Data 1). The key feedback is summarized in four aspects, shown as below.

The first part that needs to be amended is adding a process of allocating orders to different zones. According to the interviews with key informants and historical dataset, this part needs to include 7 zones: which are ALUETUKKUJAKA (ALUET), KROKEA (17), AUTOMATTI (AUTO), AKKU (14), ATOY (10), MATALA (12) and PUTKI (18). Each zone has a specific code, for example, zone 17 stores products in higher levels of shelves, normally above level 5. Zone 14 keeps heavier products, such as battery, oil and tier, which need more physical work. Zone AUTO consists of two sets of automation equipment. Currently, allocating orders is conducted semi-manually based on priority of orders.

The second point of difference happens when choosing a suitable product mover. The informants suggest it should divide into two different paths: pallet pick and plastics box pick. In addition, in the pallet pick path, special products should be operated separately, and priority of picking articles should be taken into consider.

The third part of change is about putting the product to different packing areas. According to the interviews, in the case warehouse those picked products go to three areas: shipping by own car area, packing area (Conveyor) and pick up area (Nouto). A special channel is used by pack by oneself, when products are special. These products packed by oneself are shipped directly to customers.

The last part that needs to be modified is adding the activities of receiving and shelving worker, in order to make all activities of warehouse visible and completion. This change gives two general information: one is order flowing path, and the other is products moving path. In receiving part, there are two channels to receive products: one is new products supplied by upstream partners. The other is old products returned from downstream stores.

In addition, other details of 1st version are checked and revised. For example, all numbers typed in manually are changed to scan forklift number or box number. Moreover, choosing pick lines is changed to choose pick lines by priority, and so on.

3.2.3 Final Version of the Current Picking Process

After several rounds of revise, the final version of the picking process is formed, shown in Figure 4 below.

As Figure 4 shows, the black process shows how orders flow in the case warehouse and the color words explain how the products move in the warehouse (not focused in this paper).

As for the order flowing path, orders come from the customers and are pre-processed by the sellers. After that, the orders flow to the warehouse and are allocated to different zones, which are ready to be picked. Hereafter, pickers start to pick orders following the picking instruments and putting them to packing areas. When every order is fulfilled and packed properly, they are shipped to the correspondent customers.

As regards to the product moving path (shown in red box), products are received from the upstream partners and the downstream partners, and then they are shelved to their settled location. Along with the picking process, they are transformed into packing areas and shipped to different customers.

This process includes 6 key roles. Apart from those five roles discussed in Section 3.2.1, the receiver and the shelving workers are taken into consideration. However, this process is still focus on describe the picking process in its operating aspect.

As for the customer, seller, packer and sender section, there is no change for them, shown as step 1, 2, 18, and 19. The explanations for them are the same as that in Section 3.2.1.

Figure 4 below shows the final version of the map of the picking process.

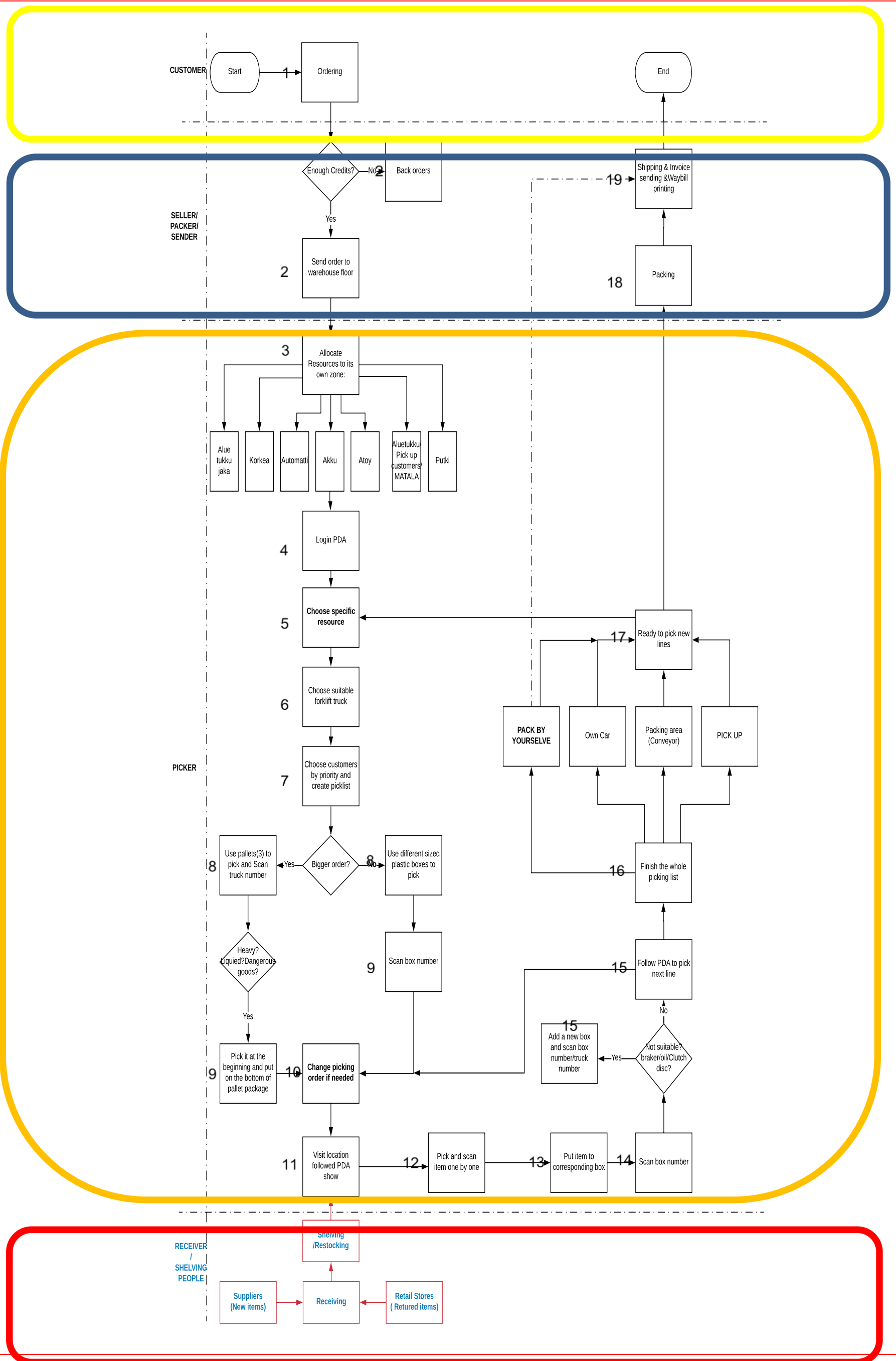


Figure 4. Final Version of the picking process.

This final version is formed and verified after double checking with those stakeholders in Data 1 collection. The supervisor of picking, who has been working in the case warehouse more than 14 years, highly praised this flowchart of picking and the mapping job.

Until now, if only discuss the picking activity, this process is the most efficient and easy-to-used one after trying out several different designs and most of obstacles of picking activity already been eliminated. In addition, this mapped process could be used as an official document when training warehouse workers.

(Supervisor of the picking activity)

According to the statement of the supervisor of picking, this final version of the picking process is successfully mapped, and all necessary steps and details are covered.

In terms of the picker part, most of steps keep the same as the 1st version (from step 4-9 and step 11-16). Taking feedback on the 1st version flowchart into consideration, some more actions are added. For example, in step 3, orders are allocated into 7 areas: ALUETUKKUJAKA (ALUET), KROKEA (17), AUTOMATTI (AUTO), AKKU (14), ATOY (10), MATALA (12) and PUTKI (18). This change is also helpful for pickers when choosing responding resources in step 5. Another change happens in step 10, adding a new step for those orders which need to change priority for some reason. Furthermore, in step 17, there are 4 options for finished pick lines: pack area by conveyor, Shipping by own car, Pick-up customers and pack by yourself. When selected “pack by yourself”, items could directly move to shipping area instead of packing area.

3.2.4 Warehouse Layout

The layout of warehouse is a super important element of picking process, especially for reducing the picking time and travel distance, However, for some reason, the official layout of the case warehouse is missed. Therefore, the author draws out a rough layout of the case warehouse (Figure 5), based on self-observation and self-measurement, along with the helps from the warehouse managers.

Importantly, the order-picking is running mostly manually. Only zone AUTO uses semi-automation system. Zone 14, AUTO and zone 18 use zone-picking methods, which means a specific picker is responsible for the whole area picking assignments. Zone 12 and zone 17 is following “S-shape” picking route. The warehouse uses Radio frequency identification(RFID) to identify the products during order-picking.

The layout of the warehouse is shown in Figure 5 below.

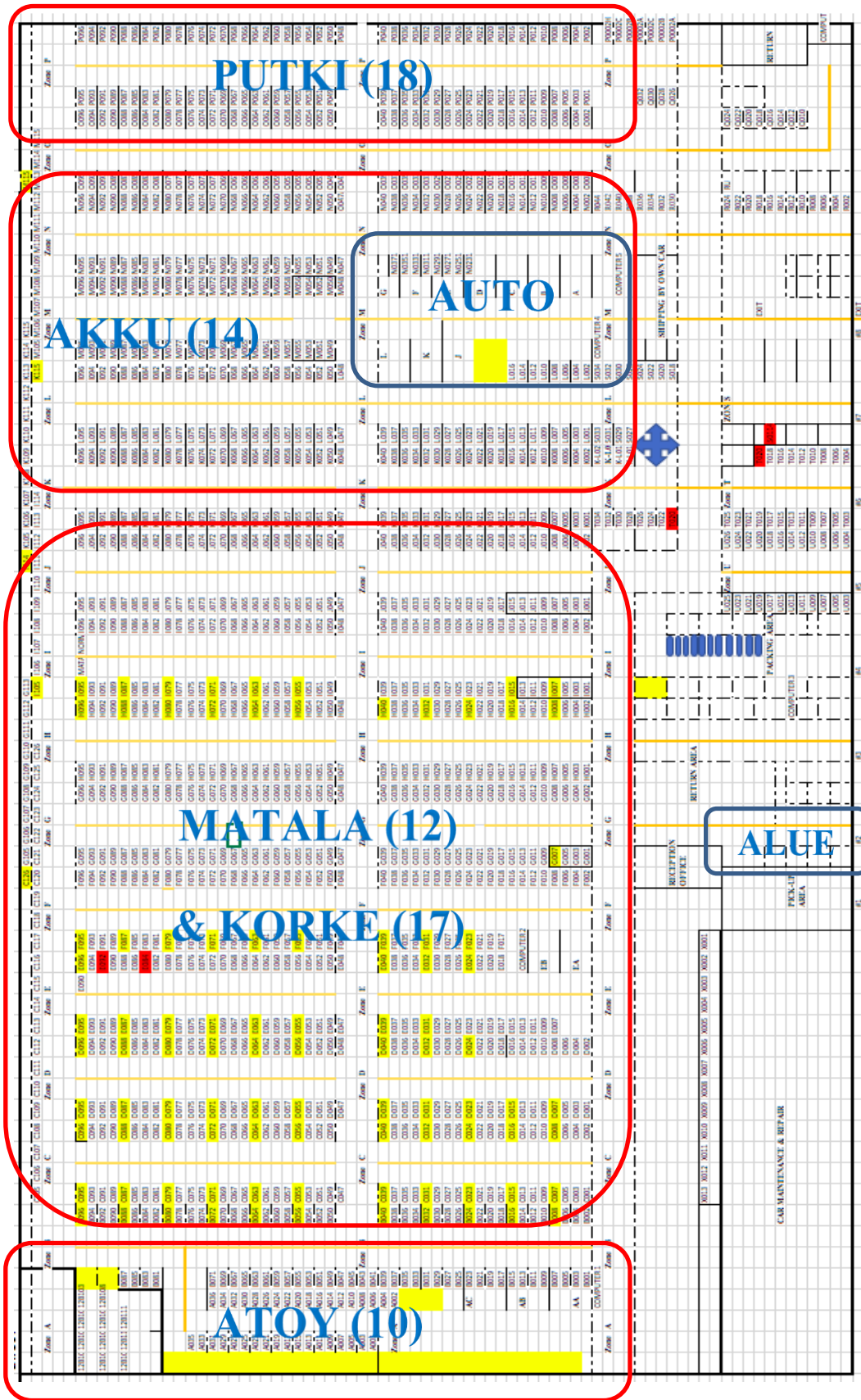


Figure 5. Layout of the case warehouse

This layout shown in Figure 5 above is drawn from a 'bird's view'. The size of warehouse is not accurate comparing to the real warehouse. But the main information needed in this study are mapped.

The red colors stand for some addresses with mistakes or problems marked by case warehouse. The blue bars mean the conveyor of packing area and the blue arrow-headed shape stands for the packing machine. Those yellow blocks without any information means places for storing plastic boxes or some other stuff (not products).

From the layout, it is clear that the warehouse is divided into 7 zones: ATOY (10), MATALA (12), KORKEA (17), AKKU (14), AUTOMATTI (AUTO), PUTKI (18), and ALUETUKUJAKA (ALUET). These names of each zone come from the raw data of the case company. Zone MATALA (12) is the biggest part of picking activity, while zone ALUET is the smallest zone. Besides, case warehouse has 16 column aisles and 3 row aisles. Each column aisle has 104 pallet addresses.

In the biggest zones, basically, zone 12 stands for lower addresses which are under level 5, while zone 17 mainly consists of higher addresses of level 6 and level 7.

Currently, the products are stored and moved in following way. Aisle F-J are fast-moving area. Aisle K and L are mainly heavier products, such as battery and oils. Aisle O and P are special products, such as irregular shape tubes. Picked products go to three different areas for next handling: shipping by own car, conveyor and pick-up area. Shipping by own car and conveyor are located in front of aisle M and aisle I, respectively, while pick-up area is close to the reception office of the warehouse.

3.3 Weaknesses and Strengths of the Current Picking Process

After mapping the verified picking flowchart, the following stage focuses on identify the weaknesses and strengths of the current picking process. According to the results of the interviews, the findings are categorized into groups. Categorizing the findings helps to find out suitable solution for addressing according process problem. All findings are based on the interviews of Data 1 collection. By doing so, not only potential weaknesses could be identified, but also some strengths of picking process of the case company.

3.3.1 Strengths of the Current Order Picking Process

The purpose of investigating strengths of the order picking process is to learn the whole picture of picking process of the case company and find out those points which are not taken into consideration in process improvements.

According to the answers of key stakeholders on what is working very well in the current picking process, the strengths are summarized and categorized into three groups: people, system & device, and product (shown in Table 2). Each of them includes detailed description and some examples.

Table 2. Summary of strengths.

No.	Description	Factor
S1	Mostly experience workers	People
S2	Strong executive force. Basically, picking process is implemented quite well	
S3	Easy-to-use and reliable warehouse system	System & Device
S4	Basically, clearness of warehouse layout and signs.	
S5	Reliable mobile equipment, like forklifts truck	
S6	Easy-to-handle products	Product

Table 2 summarizes 6 the main general strengths of the order picking process in the case warehouse. They are categorized into three groups: people, system and devices, and product. According to the statement of informants, experienced workers (S1) is the biggest advantage of the case warehouse. There are many experienced workers who works in this warehouse more than 3 years, accounting for over 60% of total workers.

Another big advantage is that most of products are relatively easier to handle (S6). In the case warehouse, most of products are light and small with regular shape, mainly stored in zone 12 and 17. Some special products are stored and operated with separate channel, such as zone 18 for tubes. This arrangement further smooths the order picking process. Some other advantages exist, too. For example, the warehouse is clearly marked, and forklift truck is relatively easy to use.

3.3.2 Weaknesses of the Current Order Picking Process

Identifying the weaknesses and strengths of the picking process is one of the most important findings in CSA. This subsection describes the weaknesses of the current order picking process. In this stage, based on theme content interviews of Data 1, the study summarizes 10 weaknesses of the current picking process in the case warehouse (shown in Table 3).

Table 3. Summary of the weaknesses.

NO.	THEME	DESCRIPTION
W1	Technical issue	1. Equipment and machines always have some problem
		2. Always need to change priority manually when pick bigger orders
		3. PDA should show basic information of closest picking lines
W2	Lack of proper training	1. Mix heavy & light items
		2. Wrong quantity of small products,
		3. Put products on forklifts, not in booked box
		4. Don't know some functions of PDA
		5. Misunderstand of Unit of measurement
		6. Don't know some products where to go
W3	Longer travel distance	1. Always choose small lines to pick and create small picklist, easier to pick, but less productivity
		2. "S" picking route in zone 12 ; sometimes pickers need to travel backwards.
		3. Not good enough planning, like warehouse arrangement & cleanness
W4	Less efficient measurement of order picking performance	1. Pickers know little about their performance, except some errors happen.
		2. Current measurement requests much work of manual calculation and is time-consuming
W5	Poor restocking accuracy	Products are not on the right place
		Empty sales places are not restocked timely

		There is no restocking list during off-peak period to refill the empty locations.
W6	Many returned products, but not re-packed properly before re-selling.	
W7	Some rules are not followed strictly, such as FIFO	
W8	Not good enough planning & signing	Some places are not marked and signed properly in warehouse, like shipping by own car & Aisle E
		Many orders come at the same time, but not enough workers;
W9	Potential risk: Putting into the wrong shipping package when “pack by themselves”	
W10	Many steps when allocating tasks and choosing resources	

Table 3 shows 10 weaknesses identified from theme content interview of Data 1. Since some questions mentioned by informants belong to the same topic, such as description of technical issues and lack of proper training, etc. In these cases, a common theme is used to formulate the question, along with some detailed description under it.

As for weakness of technical issue (W1), some descriptions are illustrated. For example, the picking process is often interrupted by machine broken, such as PDA crash or printer broken. Additionally, the current PDA is not smart enough, and always need to change the priority manually when pick bigger orders and heavier products.

The second weakness (W2) is lack of proper training. There are some symptoms of it, for instance, heavier and light items are mixed together; Quantity of products shipped to customers, especially small items, are not the same as that ordered; Pickers do not know some functions of PDA and so on.

W3 is about unproductive travelling. Pickers need to travel the whole area of zone 12 to finish pick tasks, even though for small picklist. Furthermore, Furthermore, pickers often need to change priority manually and travel backwards due to WMS cannot differentiate

the heavier and lighter items. Additionally, there are two different packing and shipping area (two depots). Thus, pickers need to consider where to go after collecting all pick lines, quite often, time is wasted on travelling between them.

Less efficient measurement of picking performance is another outstanding weakness. Currently, there is no place to show the performance of the case warehouse or pickers. Pickers know little about the case warehouse performance. In addition, current measurement work is done by supervisors, which is quite time-consuming and need much manual calculation.

Some other weaknesses are also summarized and listed in the table 3. For example, poor accuracy of restocking; plenty of returned products; picking rules are not followed properly; not good enough planning and signing; many steps in allocating resources and so on. The descriptions of them are shown in the corresponding area, along with some examples.

3.4 Current Picking Performance

In this subsection, the picking productivity of case warehouse is analyzed. According to the historical data set of 2017, the picking lines allocation chart is shown in Table 4 and Figure 6.

Table 4. Pick Lines distribution of year 2017.

MATALA	AKKU	AUTO	ATOY	KORKEA	TOTAL
392051	47339	120126	4558	16938	581012
67.5 %	8.1 %	20.7 %	0.8 %	2.9 %	100.0 %

Note: In 2017, zone AKKU (14) includes zone 14, 16, 18, 19 and 20, but now, zone 18 is separated from AKKU, and create a new zone, called PUTKI (18).

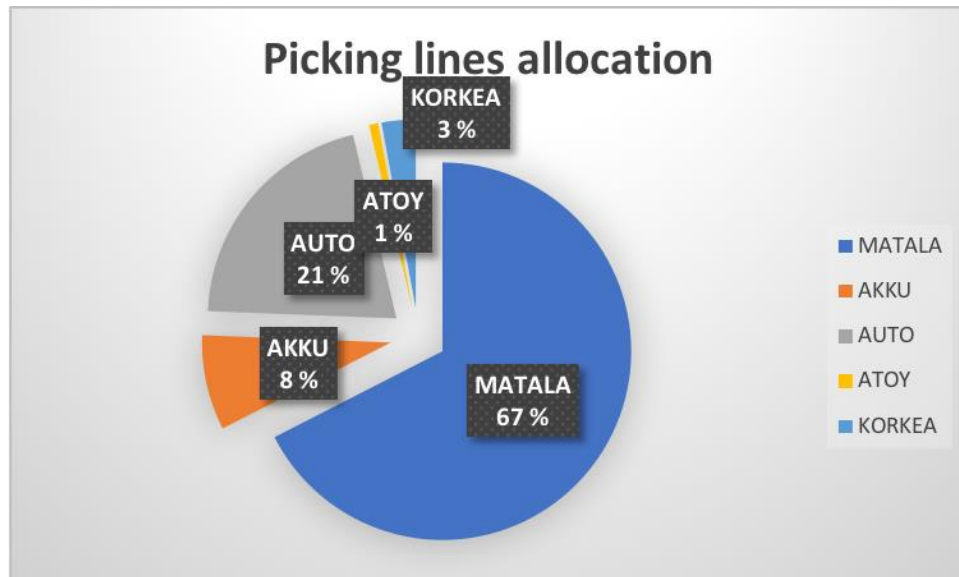


Figure 6. Picking Lines allocation.

As Table 4 and Figure 6 show, the total number of pick lines in 2017 is 581012 lines. Within it, zone MATALA (12) is the biggest component, accounting for over 67% of the total pick lines of year 2017, followed by zone AUTO, 21%. Zone AKKU (14) is the third most pick lines area, which comprise of 8% of total picked lines. There are not many lines picked in KORKEA (17) and ATOY (10) area, accounting for only 3% and 1%, respectively.

In addition, the working days of year 2017 is sorted out, shown as Table 5 below.

Table 5. Working Days of year 2017

MONTH	1	2	3	4	5	6	7	8	9	10	11	12	TOTAL
WORKING DAYS	21	20	23	19	21	21	21	23	23	22	22	18	254

As Table 5 shows, total working days of the case company in 2017 is 254 days.

According to the information above, the average lines picked per day = $581012 \text{ lines} / 254 \text{ days} = 2287.4 \text{ lines/day}$.

The working hour for picking part is also studied. Here only 4 weeks are analyzed, shown as Table 6.

Table 6. Real working time of picking.

REAL WORKING TIME OF PICKING					
	MON	TUE	WED	THU	FRI
Week 6	70:00:00	75:00:00	85:30:00	81:00:00	79:00:00
Week 7	72:00:00	64:30:00	81:00:00	68:00:00	66:30:00
Week 8	89:30:00	79:30:00	87:30:00	89:30:00	79:30:00
Week 9	72:30:00	70:00:00	70:00:00	76:30:00	79:30:00
Week 10	74:30:00	64:30:00	80:30:00	67:00:00	64:30:00
Week 11	70:30:00	73:00:00	80:30:00	79:30:00	84:30:00
Week 12	66:00:00	63:30:00	66:00:00	65:00:00	68:30:00
Week 13	63:00:00	62:00:00	60:30:00	59:30:00	/
AVERAGE	73:00:00				

As Table 6 shows, the average of picking hours per day is 73 labor hours.

Then the picking lines per labor hour = $2287.4 \text{ lines} / 73 \text{ labor hours} = 31.3 \text{ lines}/(\text{labor} \cdot \text{h})$.

The purpose of this thesis is to suggest improvements for order picking process of the case company. As findings from CSA, traveling problem in zone 12 is one of the biggest bottlenecks of picking process of case warehouse. Thus, the aisle picked frequency of zone 12 and the workload variation over time are studied, shown in Figure 7 and Figure 8, respectively.

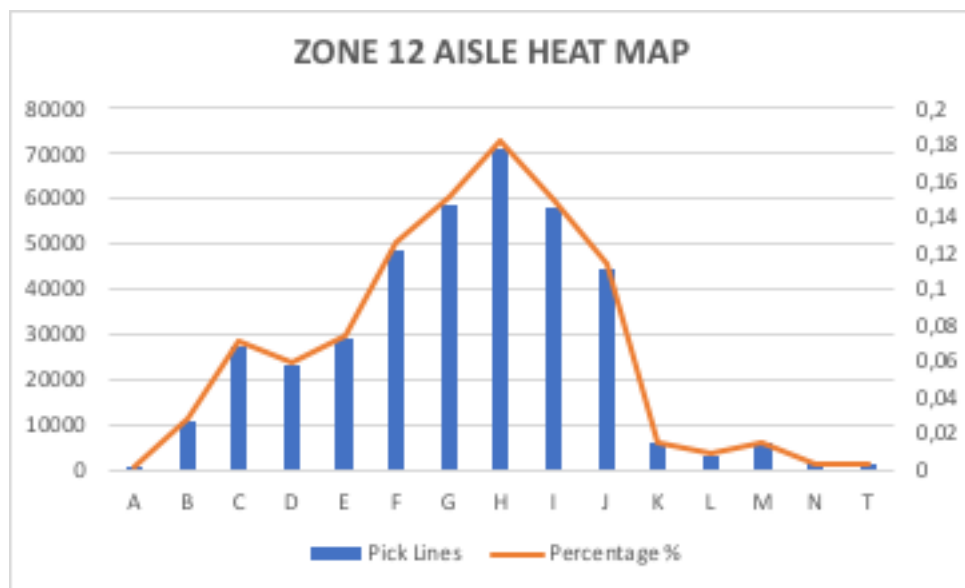


Figure 7. Aisle heat map of zone 12.

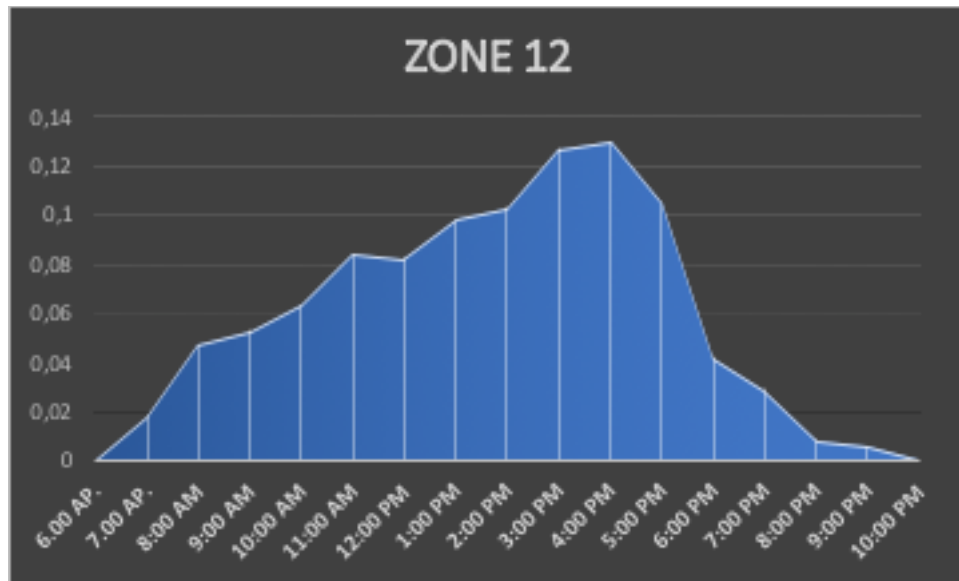


Figure 8. Workload variation of zone 12.

As Figure 7 shows, Aisles F-J are the fast-moving picking area, which accounts for 72.2% of total picking lines of zone 12, while Aisles A-E account for 23.4%, others only comprise 4.4% of it.

Figure 8 gives the information about the workload change over times during a working day. As it shows, from 1 p.m. to 5 p.m., the picking activity is the busiest period, account for more than 56% of all workload. The picking activity are very few before 8 a.m. and after 8 p.m., both of them are less than 1.8 % of total work.

3.5 Key Findings from CSA and Selected Areas for Improvement

In this section, the key findings in CSA stage are illustrated. The first outcome of CSA is precisely mapping down the current picking process. The second one is finding out 10 weaknesses and 6 strengths of the current picking process. The third one is calculating out the current picking performance, as well as aisle heat map of Zone 12.

To determine the focus of this study, a workshop with key stakeholders of the case company is conducted. During the workshop, all weaknesses and strengths identified in CSA were discussed. Through several rounds of analysis and discussion, longer unproductive travelling (W3) and less efficient measurement of picking performance (W4), were selected as the areas for improvement in this paper. As for W3, unproductive

travelling is the biggest time-consuming activity in warehouses and distributors, accounting for about 55% of the total time order picking time. Thus, all organizations spent plenty of work and time in reducing the travelling problem in order to improve their performance. Meanwhile, measurement of picking performance is another key bottleneck of the picking process in the case company. An efficient and effective measurement method could save much time and energy, as well as improving employee motivation. Combining the result of interviews with practical experience of the warehouse management, W3 and W4 are selected as the focus for improvement.

In addition, here also gives the reason why other challenges are not further studied in this paper. These days, the case company introduces a new mobile device to replace the original PDA and adopts a new shelving method to restock products. Both of them now are just in testing period. Therefore, technical issues (W1) and poor restocking accuracy (W5) are not further studied in this thesis. In addition, training on managers and workers has a separate project to study in the case company, thus weaknesses about training (W2) and implementation (W6, W7 & W9) are out of consideration. As for weakness 8 and 10, they are relatively less important and less urgent, comparing with weakness 3 and 4.

In regard to data set of 2017, there exist some drawbacks. For example, the data only has start time of picking, but no end time, which result in impossible to achieve the order cycle time. The author proposes to collect “End time” as well for later study.

Next section explains conceptual framework for addressing longer travel distance and less efficient measurement of picking performance.

4 Existing Knowledge on Improving Order Picking Process

As discussed in Section 3, the selected weaknesses for improvement are longer unproductive travelling and less efficient picking performance measurement. This section discusses existing knowledge on both of them. The purpose of this section is to build a conceptual framework to be used in establishing the initial proposal in Section 5.

4.1 Reduction of Unproductive Travelling

In a typical warehouse or distribution, order-picking accounts for around 55% of warehouse total operating cost. (Tompkins et al.1996). Generally, order picking process includes following activities: creating picklist, traveling to each product locations, searching, picking, and dropping off products. Within these activities, travelling takes the longest time, which is nearly half of total order picking time. (Tompkins et al. 2003). According to key findings of CSA, longer travel distance is one outstanding bottleneck of pick productivity in the case company. Thus, reducing the unproductive travel becomes very urgent and meaningful issue to study.

Travel problem is determined largely by two factors: storage strategy and routing policies. Storage strategy explains the rule for assigning storage addresses to receiving products, while routing policies could calculate a path which visiting all required locations. (Chan et al. 2011; Dekker 2004; Petersen 2002). In addition, it could be affected by picking method, such as zone picking and order batching, as well. (Petersen 2002; De Koster et al. 1999b; De Koster et al. 2006; Dukic & Oluic 2007)

4.1.1 Pick frequency Class-based Storage in a Warehouse

Pick frequency class-based storage means that all products are grouped to several levels and stored based on their popularity. Generally, there are some products moving relatively faster and frequent, which are often stored close to the depot and at easily accessible locations (such as front end of the rack). However, some slow-moving items also exist, which are stored further away from the depot. (De Koster et al. 1999)

Travel problem can be significantly reduced if adopt pick frequency class-based storage strategy (De Koster et al. 1999; Petersen et al. 2004; Chan et al. 2011). According to the statement of Hausman et al. (1976), up to 60% of reduction regarding travel time could

be achieved by adopting three pick frequency classes storage strategy. In some case, further reduction in travel time can be yield when applying five or six classes. However, more classes have no further impact on traveling issue. (Van den Berg 1996). According to simulation experiment taken by Petersen (2004), 2 to 4 classes is the best option in practice when using the class-based method. Because it is easier to understand and carry out, comparing to volume-based method. Furthermore, it is less time-consuming concerning administration than other dedicated methods.

In addition, Petersen and Schemmner (1999) study the effect of within-aisle storage policy and across-aisle storage policy. The results show that a within-aisle storage policy outperforms across-aisle storage policy in regard to reduction of traveling. However, sometimes, they have similar performance, for example, for small pick lists.

For any warehouse, one of the first and most important things is to find out what stock keeping units (SKUs) matter. It is quite often that 20% of products within any operation account for 80% of the activity (Bartholdi & Hackman 2017). A very popular and simple way to know this is ranking the skus by various criteria, such as picking frequency, or picking volume.

The common way for applying the pick frequency class-based storage policy is ABC analysis. ABC analysis classifies skus as three classes: A, B or C, based on the frequency of their picking within a certain interval. Class A stands for the fast-moving skus, which is not big percentage of products but account for most of the activity. Class C stands for slow-moving skus, which are quite larger portion of products while only account for a small part of the activity. Class B are those between A and C, which are moderately important. (Bartholdi & Hackman 2017; De Koster et al. 2006 ; Petersen et al. 2004)

ABC analysis could provide a theory for identifying items which have a significant impact on total cost of warehouse. Besides, it helps to classify stocks which need to different control and management. In addition, it gives a support for managers to rational allocation of limited resources and capital, such as restocking products. (Bartholdi & Hackman 2017; De Koster et al. 2006 ; Petersen et al. 2004)

4.1.2 Routing

A routing strategy has significant effect on travelling time (De Koster et al. 1999). According to De Koster and Van der Poort (1998) statement, the reductions of travel time could achieve up to 30%. Routing strategy could determine the priority that which location need to be visited firstly by the picker in a single tour. In 1983, Ratliff and Rosenthal developed an optimal routing procedure for a warehouse which includes multiple parallel aisles (without cross aisles) and a central depot. In later study, this algorithm was extended by De Koster and Van der Poort (1998). However, in practice, the most popular algorithm is simple heuristics. There are some advantages of it. First of all, it is less difficult for pickers to understand. Furthermore, the route developed by simple heuristic are consistent and easier to follow (Petersen et al. 2004; De Koster et al. 1999). In addition, in many cases, it could achieve higher performance, which is close to optimal routes, with less complication. (Hall 1993; Petersen & Schmenner 1999; Bartholdi & Hackman 2017)

Routing strategy mainly include following methods: the “S-shape” strategy, the “Midpoint” return strategy and the “Largest gap” return strategy and optimal strategy. (Hall 1993). Sometimes, the combination of them are applied based on the case environment. S-shape strategy, also called “traversal routing”, is a popular and basic method which require pickers traverse all aisles containing picks in a single direction before returning to the start point (the depot). In general, when applying S-shape algorithm, two types of picking route (single-sided picking and two-sided picking) need to take into consideration. Single-sided picking means pickers always start picking from one side of an aisle and then return back to the start point via the other side of an aisle, while two-sided picking means that pickers start picking from one end of an aisle but leave from the other end. Usually, single-sided picking is only applied when many products need to be picked in the area along with relative wide aisles. (Petersen et al. 2004; De Koster et al. 1999)

Both of the midpoint return strategy and the largest gap return strategy are requesting that the order picker start picking from one end of an aisle and always returns to the same end. The difference of them is the point of return, either from aisle midpoint or by the largest gap between two nearest locations. (De Koster et al. 1999; Bartholdi & Hackman 2017) From the study of Hall (1993), the largest gap strategy generally has better performance than the midpoint return strategy. In some situation, a combination of different routing strategy could achieve optimal solution. For example, in 1998, Roodbergen and De Koster established an optimal routing algorithm for a case

warehouse with cross aisle, via combining S-shape and an aisle return strategy for traveling within aisles.

Optimal routing comes out and become more and more widely known along with the development of computer science. Although it theoretically gives the shortest path for picking all orders, in practice, it is still hard for an order picker to implement due to pickers only have local information rather than the paths from location to location. In fact, the shorter the pick path, the more complicated the routing algorithm, which means more difficult for order pickers to understand. However, some edge technologies and solutions offer promising future for this method. For example, the 4G, even 5G technology, is extensively applied in supply chain and logistics field, which provides a reliable and stable environment for running the algorithm onsite. Additionally, some other options could make this method work better: firstly, develop a tailored path for case warehouse to generate short and easy-to-understand routes; And then, store items systematically to work with the tailored path; Finally, make local rules for order pickers to suit the tailored path. (Bartholdi & Hackman 2017)

4.1.3 Zoning

Zoning means that the order picking area are grouped into zones and each order picker works within a certain zone, for example, worker A is responsible for picking all products stored in aisles 1, ..., n_1 ; worker B is responsible for picking activity in aisles n_1+1 , ..., n_2 ; work C is in charge of picking in aisles n_2+1 , ..., n_3 and so on. Comparing with single order picking, zone-picking can significantly reduce picker's travel distance. (Bartholdi & Hackman 2017; De Koster et al. 2007)

There are various options in applying zoning. For example, establishing separate storage areas for special products, or creating a separate storage systems and handling rules for a certain area. A good example is the fast-pick area of a warehouse. In general, the most fast-moving skus are placed closest to the depot in relatively small amounts and slower-moving items are stored further away based on their popularity, Thus, most picking activities happen within a relatively small area and most orders can be finished with less unproductive travelling. Accordingly, the picking productivity could be improved. However, the fast-pick area may require plenty of restocking activities, or reserve. Therefore, the key steps to set up a fast-pick area is to decide which SKUs and how much of each of them to store there. (Bartholdi & Hackman 2017; De Koster et al. 2007)

Another way to apply zoning is subdividing a single physical storage system, such as an automation warehouse or pallet warehouse. It is common and more efficient if small products are handled by automation, while pallets products are handled separately. Because if mix all of products in a single warehouse and orders are not sorted properly, pickers need to go back to drive forklift to deal with heavier items, which causes additional unproductive travel and less productivity. (De Koster et al. 2007)

Apart from applying zoning in horizontal direction, zoning could also be used in vertical direction when placing items, via introducing a concept of the “golden zone”. Golden zone means the area between the waist and shoulder of a person. According to the study of Petersen (2005), order picking time could be significantly reduced when storing fast moving items between the waist and shoulders of pickers. (Petersen et al. 2005)

However, there exist some challenges of zone configuration (Petersen et al. 2002; Jarvis & Mcdowell 1991; Huber 2014). Many factors have effect on zone configuration performance, such as the size of the picking zone, the storage strategy, and the number of items need to be picked and so on. But, the extent of the effect varies case by case. According to Petersen’s study on zone configuration, grouping three to four aisles in a zone is a good option for large picking zones and small pick lists, because it could reduce pickers unproductive travelling. While, as for small picking zones and large pick lists, two options could be utilized. One option is introducing a one-aisle zone if the warehouse without cross aisle. The other way is adopting two-aisles zone if the warehouse with a back cross aisle. (Petersen et al. 2002). Just as certainly, congestion only happens when multiple pickers work in the picking area at the same time. If only one order-picker in the system, then it is not a problem. In zoning system, each picker is only responsible for a part of an order. The partial orders are united into a complete order, either along with the picking activities through zone by zone, or after each zone picking. (Jarvis & Mcdowell 1991).

4.1.4 Order Batching

Order batching is a method extensively applied in order picking process. It divides a group of orders into many sub-groups based on a common rule, such as customers or shipping schedules. The purpose of batching orders is to retrieve orders as many as possible in a single picking route, which means less unproductive travelling and higher picking performance. The items which are grouped in the pick tour via order batching

have to be consolidated into a complete order. Similar as zoning picking, the sorting activity could be done along with picking or afterwards. (De Koster et al. 1999, 2007)

The difficulty of order batching is to find out which orders can be grouped together and effectively so as to achieve the minimal travel time. Based on the statement of Choe and Sharp (1991), the proximity of pick locations and time windows, are two most popular criteria and batching method in practice. The proximity batching is a method which combine orders into different batches on the basis of the nearness of their storage locations. Generally, those orders with close storage locations are assigned together as a batch. While time window batching groups orders based on the arriving time or shipping schedule during the same time interval as a batch. The time interval could be a fixed period or a variable length. According to the study of De Koster on simulation experiments, the results show that time window batching approach outperforms the proximity batching regarding to accuracy level. In addition, it is relatively simpler and easier to be implemented in workplace. (De Koster et al. 1999, 2003, 2007)

Order batching is a difficult issue and plenty of researches try to invent new heuristic methods to solve it. According to De Koster et al. (1999), there are three heuristic algorithms applied in the batching: first come first served algorithm, seed algorithm, and time savings algorithm. As for the first come first served algorithm, orders are combined to picking routes in turns based on their arriving time, until the capacity of the pick device is achieved. Seed algorithms consists of two main steps: firstly, selecting an order via a seed selection rule, which has not yet been included in a route; Next, add orders one by one with an order addition rule, until the capacity of the pick device is achieved. The purpose of time savings algorithms is to minimize the total picking time. It combines orders only if time saving can be achieved, comparing to executing them separately. It requests to calculate the time saving for each pair of orders. Furthermore, a routing algorithm need to be considered when applying this method. (De Koster et al. 1999, 2003, 2007)

4.2 Picking Performance Measurement

It is difficult to evaluate the picking performance based on daily observation since warehouse activities are always fast-moving and operated over a large scale. However, it is possible to make inference of warehouse activities from a historical picking data together with a layout of a warehouse. This historical data need to be carefully analyzed

following a statistical way and the results need to be interpreted properly. Luckily, new technologies and management skills give a strong support to the warehouse managers for warehouse daily operating, such as visualization management. (Bartholdi & Hackman 2017).

The core ideas mentioned in this section are mostly based on a book wrote by Bartholdi and Hackman (2017) which gives a detailed explanation on order picking process as well as warehouse designing and management. Further details are applied below in relation to the focus area.

4.2.1 KPIs of Performance Measurement

Generally, warehouse performance could be measured by a ratio (taking output together with required input into consideration)

$$\frac{\text{Units of output achieved}}{\text{Units of input required}}$$

This ratio has various interpretation. (Rogers 1998; Bartholdi & Hackman 2017; Galka et al. 2008) Usually it could be substituted as one of the following key indicators: Operating cost, Operating productivity, Order-cycle time, or Order accuracy (measured as proportion of shipments with returns). Operating cost could be measured by warehouse costs as a percentage of sales. Order accuracy is measured as portion of shipments with returns. While there are several indicators of operating productivity, such as pick lines per labor hour, pick orders per labor hour, or cartons/pallets handled per hour. (Bartholdi & Hackman 2017; Lee et al. 2016)

Ideally, a measure of productivity need to be unbiased, customer-focused, and consistent with corporate strategy. However, in reality, most of the key performance indicators(KPI) mentioned above do not meet these criteria perfectly. For example, “warehousing costs as a percentage of sales” is biased because the percentage relies on not only warehouse part, but also sales, which could be affect by marketing. In addition, it contributes nothing to customer-focused. “proportion of shipments with returns” heavily depends on the third party of logistics and do not consider whether the correct items were shipped.

Warehouse activity is driven by customer orders; each customer order is a shopping list comprised of “pick lines”; and each pick line involves a string of warehouse activities:

visit to the appropriate storage location and subsequent picking, checking, packing and shipping. Therefore, pick lines are then a key indicator of warehouse activity.

Order cycle time reflects how quick a company respond to their customers' needs. In today's service-oriented business, the shorter the respond time, the better customer satisfaction, as well as the better market competitiveness. Thus, order cycle time is often used as a key indicator for many warehouse managers.

Therefore, in practice, pick-lines per labor hour (or per day) and order cycle time are two popular and main performance indicators, although they are also not perfect ones.

4.2.2 Warehouse Activity Profiling

For any organization, no matter to retrofit an existing warehouse, or build a new warehouse or distribution center, fully understanding the work activity of the case warehouse is a prerequisite of any improvements. The organization must analyze the patterns of customer orders and how this affect the workload within the organization.

Warehouse activity profiling is a careful measurement and statistical analysis of warehouse activity. Generally, it is an essential first step to nearly any significant warehouse project. There are mainly four key steps to do the profiling for a warehouse: data collection, data mining, cross-checking, and results interpreting. (Bartholdi & Hackman 2017, Chapter 14)

First, regarding *the data collection*, there are four main types of data required to support profiling: data relevant to each sku, Data relevant to customer orders, data relate to locations and data relevant to working times within the warehouse. Generally, warehouse management system(WMS) could provide the historical record of picking process, which includes most of these information, such as SKU data, order history, location addresses, pick lines and volume, etc.

According to the historical picking data, it is easy to know currently how it is distributed among skus, product families, storage locations, zones, and time (time of day, days of the week, weeks of the year, and so on).

Another very important document is working arrangement. From this document, it is easy to get how many hours each picker works per day, what kind of work he or she has done, averagely how many pickers are needed per working day, and so on.

Second, regarding *the data mining*, nowadays, plenty of new technologies and software are used for data mining, such as big data, QUEST system, etc. However, there is no universal software which could be applicable to all warehouses. Because each warehouse seems to be different and unique and it is nearly impossible to standardize on a general level.

Although there is no standard way to do data mining, some essential abilities are listed out as following: sort the rows of a table, choose rows, count distinct entries in a table, connect the rows from different tables and graph results.

Some useful and easy-to-use software could be applied for data mining, like Structured Query Language(SQL), MS Excel, etc. The selection of software heavily depends on the situation of case companies. MS Excel is the basic and but applied commonly for relatively small sized data mining. The key functions of MS Excel used for data mining are Filter, Slot, PivotTable, PivotChart, Count, Sum, Average, Conditional Formatting.

Third, regarding *the importance of cross-checking*, discrepancies appear frequently in raw database, which asks for having a strategy for dealing with them. A very common way to address this problem is that first identify them and then document their severity. If it is just a small problem, it can be ignored due to the purpose of warehouse profiling. But IT staff need to be informed to fix it.

Another way to reducing problems is energetically cross-checking all data and analysis. To avoid bias and inconsistent, some methods could be taken into account, for instance, asking the same question in different way, different point, or solving the same problem through different sources. Carefully checking every calculation and result could make sure achieving a consistent answer. Paying more attentions and cares when check the busiest SKUs, locations, times and so on, since errors tend to appear at the extremes of these areas.

Finally, regarding *the interpreting patterns*, interpreting the data and results is of importance in data mining because this part is easy to cause bias and make mistakes. Some points need to pay more attentions, for example small numbers and sampling biases.

Small numbers sometimes have a strong meaning. For example, 0 does not always mean nothing, sometimes it is a code of picklist or box. If few orders are picked unusually slowly, then the average of order cycle time will significantly increase, which mislead the

analysis. Thus, to show the real situation happened in warehouse, the researchers need to find out those special cases at first and then document them properly for further analysis.

Sampling biases is another common problem in interpreting patterns. For example, when calculating how many lines picked per labor hour, it heavily depends on what kinds of products picked, as well as who and when do the work. Product weight, storage locations and the content of lines also affect picking productivity. Therefore, when set a standard of picking productivity, the decision-makers need to consider different elements relevant to picking productivity and choose larger sample to get a reasonable and meaningful result.

4.2.3 Visualization

Historically, visualization refers to a graphical representation of data or concepts and is used to establish a mental image, but now, it becomes much more meaningful, which could provide not only mental image and concepts, but also insights of data and business knowledge under critical analysis on a computer screen. (Manuela & Costa 2014; Bikakis 2018)

In general, visual analytics is a repeating process which includes data collection, data integrating, data mining, knowledge representing, interacting, and decision making. The main purpose of visual analytics is to obtain insight into the business challenges faced by the organization. Usually, those business challenges are described by plenty of data from different sources. To achieve this objective, it is important to combine the advantages of the computational power of newest computers and strengths of humans. Heat map in a warehouse is one example of visual analytics applied in the real workplace. (Keim et al. 2006; Kopp et al. 2013; Bartholdi & Hackman 2017; Tufte 2001)

One important and necessary step of visual analytics is data graphics. According to Tufte (2001), data graphics use multiple tools (such as points, lines, numbers, words, tables, shading and color, etc.) to show measured quantities. It is one of the most effective method for describing, summarizing and reporting quantitative data. Historically, data graphics is mainly used to replace conventional tables of numbers. However, modern data graphics is developed dramatically and extend out of the traditional functions. In most cases, graphics could be used as a key instrument in mining quantitative information and help managers in daily operation and management. (Tufte 2001)

In big data era, visualization is commonly applied in the daily management. Modern visualization and exploration systems provide more effective and efficient solutions in real-time interaction, on-the-fly processing. (Bikakis 2018; Liu et al. 2014; Rocha-Doria et al. 2017). Many front-line managers have a consensus that well-designed data graphics are usually the simplest and simultaneously the most powerful way for analyzing and communicating statistical information. In addition, it supports managers to understand their team performance better and provides reliable proof for decision-making. For example, the visualization of worker performance could help managers identify the weaknesses in time and accordingly think out a suitable solution to fix it. Furthermore, graphics could directly tell how workers perform at this point. Visualization of statistical data is a fairly recent phenomenon and its power comes from engaging and augmenting the human in the loop, rather than replacing them. (Manishankar et al. 2018; Kopp et al. 2013)

Thus, in regard to implementation of visualization, some general principles can be summarized based on Tufte 2001; Bartholdi & Hackman 2017: Firstly, utilize graphs to show large scale patterns, especially when making comparison with other patterns. Secondly, use percentages to show the big picture instead of the original numbers and use tables for closer looks some important numbers. The last but not least is that scale the information to make it easier to understand. For instant, it is better to report average lines per day rather than total lines over the study period.

4.3 Conceptual Framework of This Thesis

In this section, a conceptual framework of this thesis is drawn out. This conceptual framework is further applied in Section 5 to establish a proposal for improving the weaknesses identified in Section 3. This framework consists of two main topics: reduction of unproductive travelling and measurement of pick performance, as shown in Figure 9 below.

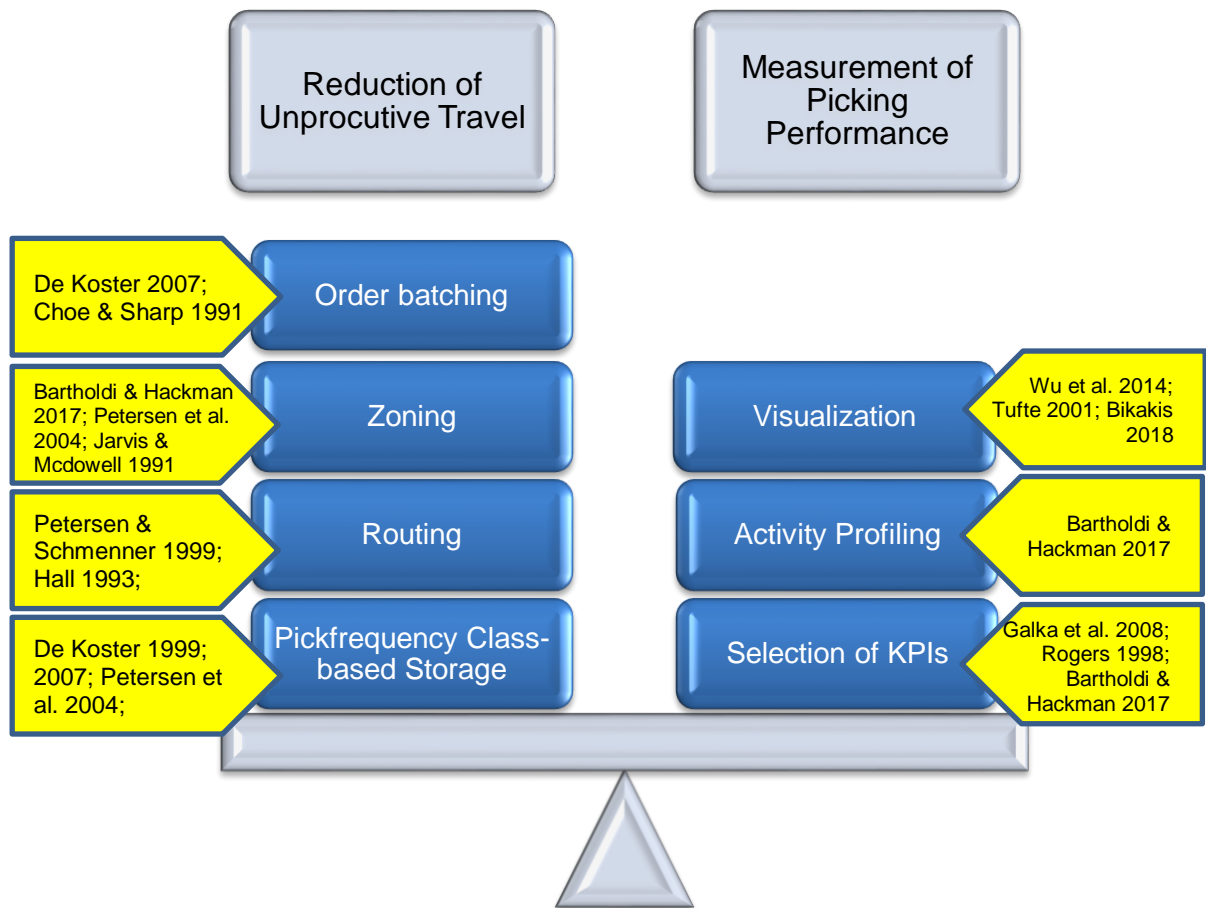


Figure 9. Conceptual framework for improving order picking process.

The first half part of conceptual framework focus on reduction of unproductive traveling of order picking. It consists of the storage strategy, routing policy, zoning and order batching. According to the existing knowledge, pick frequency class-based storage strategy has great beneficial over others, with regards to traveling issue. A good example is application of heatmap of warehouse via historical data. Combination of different routing policies are extensively applied in practice based on concrete case situation. In addition, zone-picking, especially re-slot fast-moving area, is a necessary step to reduce travel distance. Furthermore, order batching contributes plenty of savings for reducing unproductive travelling, such as grouping many orders in a pick tour.

The second half part of CF focus on measurement of picking performance. It starts from selecting KPIs for picking performance measurement, followed by building the warehouse activity profiling. As mentioned in Section 4.2.1, picking line per labor hour and order cycle time are most popular indicators in measuring picking performance. In building warehouse activity profiling stage, a statistical method for data analysis is reviewed, which includes data collection, data mining, cross-checking and pattern

interpreting. Finally, visualization, as an important method for daily operational management, is introduced. Real-time interaction and on-the-fly processing are applied in big data era to help managers to improve daily operation management.

Summing up, in this section, many useful and practical tools of operating management and data analysis are reviewed, which forms a systematic and tailored theoretical foundation for further study. Next section tells about the initial proposal development built on combination of the key findings of CSA and conceptual framework.

5 Building Proposal on Improving the Picking Process of the Case Company

This section describes the initial proposal building by merging the key findings from the current state analysis (Section 3) and suggestion summarized in the conceptual framework (Section 4), as well as a second round of data collection (Data 2). The purpose of this section is to build an initial proposal for improving the order pick process of the case company.

5.1 Overview of the Proposal Building Stage

In Section 3, two selected areas for improvement were identified, which are (a) longer unproductive travelling and (b) less efficient picking performance measurement. Thereafter, Section 4 explored the existing knowledge to address these two selected weaknesses.

According to the results of the current state analysis, performance measurement and travel distance are identified as the focus of improvement of picking process. Accordingly, in Section 4 conceptual framework, based on the relevant existing knowledge of these two elements found from literatures was drafted. For example, in terms of travel distance, warehouse storage strategy, picking methods and routing play an extremely important role in reducing travel distance, especially pick frequency class-based storage strategy. As for the picking performance measurement, the pick lines per labor hour (or per day) and the order cycle time are two popular and useful indicators of picking performance. In addition, visualization of KPIs is a useful and effective way for improving picker's productivity.

The initial proposal is formed based on theme content interviews (Data 2) and application of the conceptual framework to the case company in order to solve the picking process problems. Accordingly, the proposal building process is divided into two main parts.

In part one, author conducts face to face theme interviews and workshops with key stakeholders, which includes the warehouse manager, picking supervisor and 2 experienced pickers (5 y+). Based on the content of the interviews, relevant suggestions are grouped and documented, which is ready for further analysis.

In applying the conceptual framework part, the author firstly collects the picking data of year 2017 and April 2018, and then follows the instructions of conducting a statistical analysis, which was discussed in Section 4.2.2, the conceptual framework building. Every calculation is double-checked by key stakeholders and cross-checked by other data. Thus, the initial proposal is a valuable and sufficient data-based decision making.

One highlight of this part is that key stakeholders are involved in the proposal building. They provide valuable and practical clues for solving problems (Discussed in Section 5.2). Most suggestions offered by key stakeholders are studied and analyzed via statistical analysis and some of them are adopted and applied in drafting initial proposal.

5.2 Findings of Data Collection 2

In this section, Data 2 is collected and analyzed. Data 2 consists of suggestions from key stakeholders for dealing with the identified weaknesses. The summary of key stakeholder suggestions is shown in Table 7 below.

Table 7. Key Suggestions for proposal building (Data 2).

	Key focus area from CS (from Data 1)	Suggestions from stakeholders, categorized into groups (Data 2)	Description of the stakeholder suggestion
1	Longer Travel Distance	<ol style="list-style-type: none"> 1. Re-slot warehouse layout 2. Zone picking 3. Batch more lines within a pick route 	<ul style="list-style-type: none"> –Calculate the pick frequency of each location from a bird's view according to the historical data. –Group items based on product family or picking frequency. –One person should be responsible for a certain zone, especially the fastest-moving area, in order to reduce unnecessary travel and congestion. –The bigger orders and smaller ones should be handled separately and increase the picklist size as much as possible.

2	Less Efficient Performance Measurement	<ol style="list-style-type: none"> 1. Set proper evaluation standard of each work/zone. 2. Visualize performance and evaluation standard. 	<ul style="list-style-type: none"> –Analyze the historical picking performance and set an evaluation standard for each area. –The picking performance should be visible to all pickers and the evaluation standard should be practical and achievable. –Set a proper start time for each picking, in order to reduce less efficient work.
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As Table 7 shows, the suggestions are categorized based on the CSA focus areas and the CF elements. As regard to less efficient performance measurement, the warehouse manager also suggested that KPIs and pickers performance should be visible to all pickers in time by installing a screen to warehouse wall. Apart from that, he called for setting a proper evaluation standard for each zone using one or two indicators (such as picking lines).

Every zone should have a specific evaluation standard. For example, Zone MATALA ja Zone T should pick at least 50 lines per labor hour; zone AKKU (14) is 20 lines/hour, zone AUTO is 72.5 lines/hour. zone KORKEA is 20 lines/hour, zone ATOY is 15 lines/hour, and zone PUTKI is 25 lines/hour. These numbers come from benchmarking with myself. (Warehouse manager)

In addition, he suggests that each picking line should have a proper start time because historically some urgent lines are not picked timely, while those less urgent ones are picked too early.

In terms of a longer travel distance, key stakeholders suggest that zone-picking and suitable storage policy (pick frequency class-based storage) should be used. Furthermore, re-arrange warehouse layout based on the heatmap of each aisle is necessary step, especially in zone 12.

It should be better if items are stored close to the packing area based on its picking frequency, or the same family products are stored close to each other, such as brake discs and brake pads, which pickers do not need to spend more time on traveling. According to the heatmap of aisles, maybe it is better, if divide zone 12 into three groups: A-F(moderate), G-J (faster) and K-U (slower). (Warehouse manager)

Apart from benchmarking with the warehouse manager, the evaluation standard for each zone could be calculated out according to pickers' performance. However, this work calls for IT staff adding new function when collecting picking data.

5.3 Reduction Unproductive Traveling

In this section, statistical analysis is conducted following instructions of Section 4.1.2. It includes re-arrange warehouse layout, ABC analysis and order batching rules.

5.3.1 Pick frequency class-based storage strategy

According to the suggestions from the conceptual framework in Section 4.1.1, the pick frequency of each pallet location is calculated based on the historical picking data.

In Figure 10, the heat map is drawn from a bird's view, and the number of each location is a total amount of several small addresses. For example, the number of location F025 is the total amount of address F025AA, F025AB, F025AC, F025BA, F025BB, F025BC, ..., F025GA, F025GB and F025GC. These small addresses are used to store small and limited quantity of products. Some of them are used to store moderate sized products, which normally include 4 levels and each level has two addresses. for example, G038 stands for G0381A, G0381B, ..., G0384A and G0384B.

In this map, different color stands for different groups and it includes 5 groups based on the frequency of pick lines during the year 2017, which is more than 2000 lines (dark), 1000-2000 lines (red color), 500-1000 lines (yellow), 300-500 lines (blue) and less than 300 lines (no color). Figure 10 below shows the heatmap of zone 12.

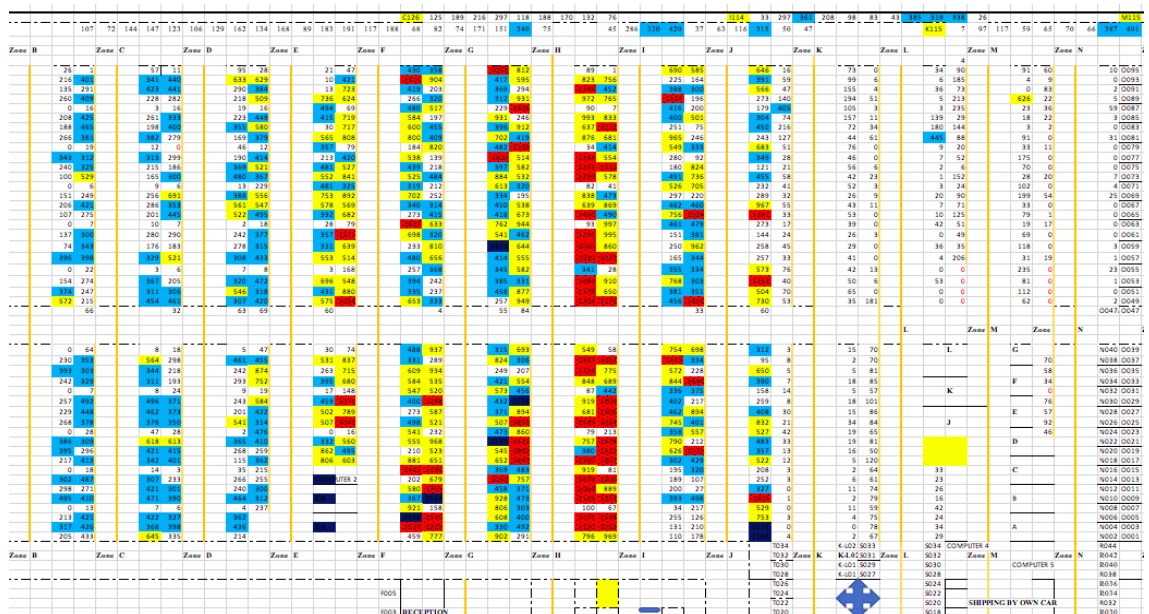


Figure 10. Heat map of zone 12.

From the heat map, it is clear that case warehouse consists of two parts: front part and back part. Basically, it follows pick frequency class-based storage strategy. The fast-moving products are stored in aisle F-J (closer to packing area), moderate ones are in aisle B-E, slower ones are in aisle K-N.

In the other side, the case company did not follow this strategy well in reality. For example, in address M090, there are 626 lines picking during year 2017, and all these lines come from address M0902B (item DA460785). According to pick frequency class-based storage strategy, it should be stored between aisle F-J. Similar situation happens for address L082 (445 lines).

Furthermore, those locations, which are close to the back wall, are very far away from the packing area, but some of them have more than 300 lines (even over 400 lines) picked in 2017, such as M112, M113, K107, K112, K113, K114. These addresses definitely increase the unnecessary travel distance so as to decrease picker's productivity.

In addition, within aisles, products storage still need to follow pick frequency class-based strategy. Faster-moving items are close to the two ends of aisle and located in "golden zone".

5.3.2 ABC Analysis

The concept of ABC analysis is discussed in Section 4.1.1. In this sub-section, ABC analysis is applied in the case company and conducted based on picking data of year 2017. In total, there are 39101 different kinds of items are picked and shipped to customers during the whole year, which are located in around 31980 addresses. Here the author defines that those items whose pick lines per day is bigger than 3, belong to Class A. Those picked between 1 and 3 lines per day, belong to Class B, others are Class C, Thus, the distribution of items are shown Table 8.

Table 8. ABC distribution.

Class	A	B	C	TOTAL
Pick lines/day	≥ 3	$1 < x < 3$	≤ 1	
Quantity	36	249	38816	39101
Percentage	0.09%	0.64%	99.27%	100%

Table 8 shows that most of items belong to Class C (picked less than 1 line per day), accounting for around 99%. Only 0.09% of products are picked more than 3 lines per day. And 0.64% of products belong to Class B, which picked between 1 and 3 lines per day. In other word, in the case company, most of products are kept in small volume and traditional “20/80” rule is not fit for the case company.

Here, 36 Class A items can be identified based on the historical picking data. (shown in Table 9). They account for 7.22% of total picking frequency and 6.36% of total picking pieces.

Table 9. Class A items.

LINES /DAY	Accumulative	ITEM	Accumulative	PIECES /DAY
10.3	0.45 %	OE673	0.36 %	19.3
10.2	0.90 %	K1111	0.65 %	15.6
9.0	1.29 %	OE650/1	0.98 %	18.4
8.1	1.65 %	OP595	1.27 %	15.5
6.7	1.94 %	OP572	1.56 %	15.7
6.6	2.23 %	OP575	1.76 %	11.0
6.3	2.50 %	OE667/1	1.97 %	11.0
6.3	2.78 %	OE688	2.17 %	10.8
4.8	2.99 %	OP526/1	2.32 %	8.3
4.3	3.17 %	OP617	2.46 %	7.5
4.2	3.36 %	OP641	2.60 %	7.4
4.2	3.55 %	OP540/1	2.74 %	7.9
4.1	3.72 %	OP532/2	2.87 %	6.9
4.1	3.90 %	OE662	3.03 %	8.6
4.0	4.07 %	OE640/5	3.19 %	8.5
3.9	4.25 %	GDB1330	3.30 %	6.4
3.9	4.42 %	K1210	3.41 %	5.8
3.9	4.59 %	2201255	3.52 %	5.9
3.8	4.75 %	OP629/1	3.63 %	6.1
3.7	4.92 %	PL56240	3.88 %	13.1
3.6	5.07 %	2201225	3.97 %	4.9
3.6	5.23 %	FB15374	4.46 %	26.6
3.5	5.38 %	PE973/3	4.55 %	5.1
3.5	5.53 %	OE677/4	4.65 %	5.4
3.4	5.68 %	OE648/6	4.75 %	4.9
3.4	5.83 %	PL60038	4.94 %	10.8
3.4	5.98 %	K1150F	5.03 %	4.9
3.3	6.13 %	D24	5.23 %	10.6
3.2	6.27 %	2201545	5.31 %	4.3
3.2	6.41 %	AP139/2	5.40 %	4.7
3.1	6.55 %	OE685/2	5.47 %	4.1
3.1	6.68 %	H3	5.66 %	10.0
3.1	6.82 %	OP641/2	5.73 %	3.6
3.1	6.95 %	K20TT	6.09 %	19.9
3.0	7.09 %	PL57512	6.25 %	8.5
3.0	7.22 %	OE662/1	6.36 %	6.0

As seen from Table 9, and comparing with heat map of the aisles, all these class A items are located in dark or red color addresses. These items include various filters, brake pads, batteries and so on.

5.3.3 Routing and Zoning

The concepts of routing and zoning are illustrated in Section 4.1.2 and Section 4.1.3, respectively. This subsection discusses the application of these two methods in the case company in order to establish a tailored solution for improvement.

In the case warehouse, the current pick routing is mapped in Figure 11. As it shows, there are two depots (shipping areas) in case warehouse. Depot 1 is for sorting and packing area via conveyor, Depot 2 is shipping directly to customers by own cars (without packing). Basically, case warehouse uses two-sided S-shape routing strategy. Pickers start picking from depot 1 and go through all aisles from left side to right side. After finishing all picking task, they have to decide which depot to drop off the picked items, either go back to depot 1 (green color arrow) or depot 2 (grey color arrows). During the peaking time (from 1 p.m. forwards), the automatic area is forbidden for driving through. Figure 11 below shows current routing of the picking process in the case warehouse.

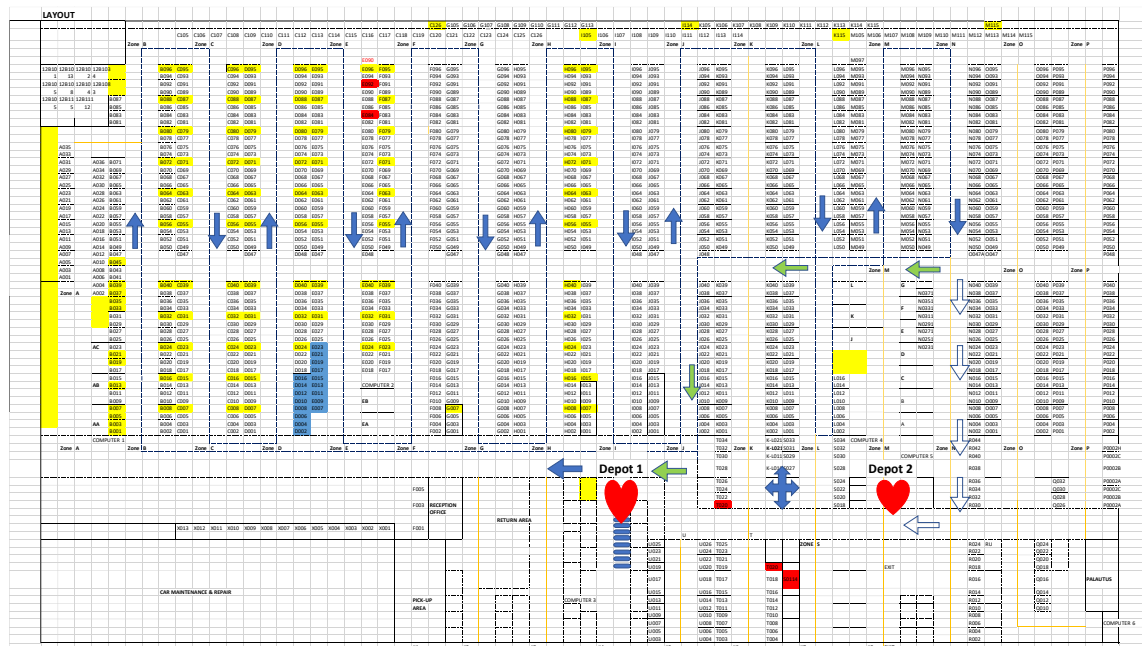


Figure 11. Current routing of the picking process.

According to the analysis of the picking data of year 2017, there are only 7 locations picked more than 2000 lines and 66 locations picked between 1000-2000 lines within the whole year. In addition, 36 Class A items are sorted out. If firstly rearrange all of these fast-moving products into two near aisles (such as G-H), and choose one picker responsible for picking them, it could save plenty of travel distance and time, as well as

avoiding congestion. Furthermore, within an aisle, it is better to recommend that all Class A items are re-located in Golden zone and close to the packing area.

Basically, Zone 12 could be divided into three sub-zones: Mid-moving items (A-F), fast-moving items (G-J), and the slower moving ones (K-U). Each of them adopts zone-picking and 'pick-and-sort'. In addition, combine depot 2 and depot 1 to one location (close to depot 1). Thus, pickers in each zone could drop off picked items on an extra conveyor for further sorting and packing as (shown in Figure 12).

In terms of routing in each sub-zone, it mostly keeps the same as before, using two-sided S-shape strategy, since it is easier to understand for pickers. For the slow-moving zone, there is no strict routing rule, so that the pickers could plan its route path based on their different picking task. As shown in Figure 12, an improvement of routing is formed via introducing zoning.



Figure 12. Improved routing and zoning of the case warehouse.

5.3.4 Order Batching

The concept of order batching is explained in Section 4.1.4. Based on the ideas from existing knowledge for order batching, the picker's performance and picklist size are analyzed, with regard to picking time per line. These data come from the picking data of 04.2018. After adjustment of the data collection method, the end time of each pick activity

is collected now. Thus, the current picking time per line is calculated in relation to each picker, shown as Table 10.

As Table 10 shows, the average of picking time per line for all pickers is 1 min 50 seconds. The fastest picker spends only 43 seconds per line, while the slowest one spends more than 3.5 mins per line. There are four pickers with relative lower picking performance, spending more than 3 min. for a picking a line, which are picker 117,119,123,179.

In addition, it also shows picking time heavily depend on which zone the picker is working in. For example, the fastest picker mainly works on zone AUTO, the slowest one is mostly in zone ATOY and AKKU. In zone MATALA, generally pickers spend around 1.5 minutes for picking a line.

Table 10. Picking Time/Line for all pickers in 04.2018.

Picker	Time consuming/line (AVG.)	Picker	Time consuming/line (AVG.)
104	0.01.13	154	0.00.43
106	0.01.11	161	0.03.24
111	0.02.41	165	0.00.52
113	0.01.00	166	0.01.20
117	0.03.49	170	0.01.34
119	0.03.08	174	0.01.26
123	0.03.45	177	0.02.12
124	0.01.26	178	0.01.11
125	0.01.21	179	0.03.45
131	0.02.02	182	0.02.06
133	0.02.04	183	0.01.49
135	0.01.42	184	0.01.24
136	0.02.32	185	0.01.32
137	0.00.56	186	0.01.08
140	0.01.42	187	0.01.02
148	0.01.29	189	0.01.18
149	0.01.52	400	0.01.45
AVERAGE		0.01.50	

In order to find out the relationship between picking performance and the picklist size, here the author chooses two representatives in zone MATALA to analyze their performance. Picker 111 is a newcomer, standing for “slower one”, and picker 174 is a more than 3 years picker, standing for the “faster one” of zone MATALA. The trend of picking time/line along with picklist size is drawn as below (Figure 13 and Figure 14)

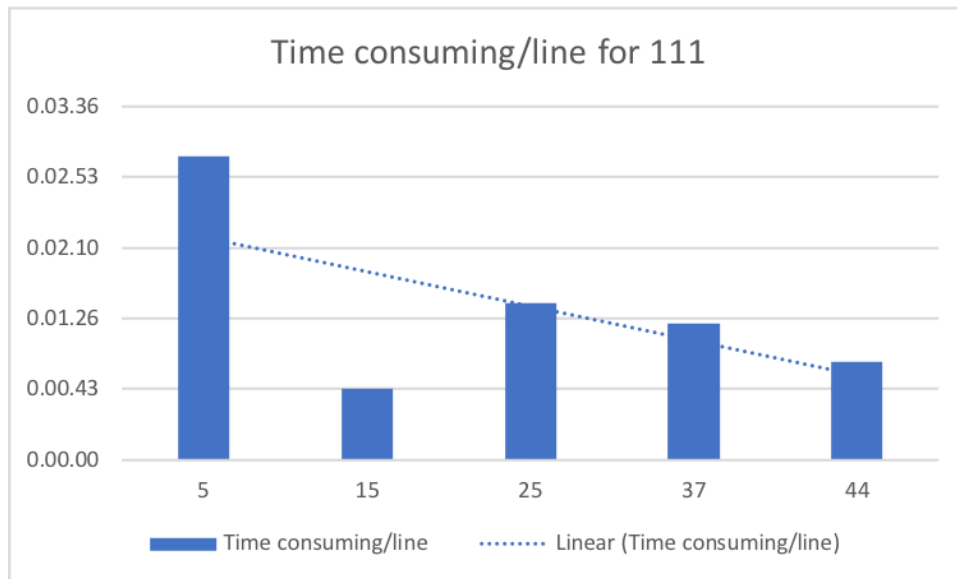


Figure 13. Picking Time/Line for the picker 111.

As Figure 13 shows, generally, the picking time/line decreases along with the increase of the picklist size, except of 15 lines (extremely fast picking). Furthermore, when the picklist contains 44 lines, the picking time per line is below the average level of “faster picker”.

In addition, the study also zoomed into one special case of this chart and found out the content of 15 lines, shown in Table 11.

Table 11. Picklist content of size 15 for the picker 111.

RESURSSI	AREA	LOCATION	RIVIT
MATAL111	12	D057DD	1
MATAL111	12	G0221A	1
MATAL111	12	G0291A	1
MATAL111	12	G0742B	1
MATAL111	12	G0783B	1
MATAL111	12	H0152A	1
MATAL111	12	H0511B	1
MATAL111	12	H0514B	1
MATAL111	12	H092FB	1
MATAL111	12	I0262C	1
MATAL111	12	I0981	1
MATAL111	12	J0271A	1
MATAL111	12	J0494A	1
MATAL111	12	J0494A	1
MATAL111	12	J0645A	1

As Table 11 shows, the address of this picklist is mostly close to each other, the picker does not need to travel too much, except the first location: D057DD. Even for a newcomer, if the locations of products are arranged logically and properly, the picking

time could be saved dramatically. In some way, this finding further supports for re-slotting fast-moving items.

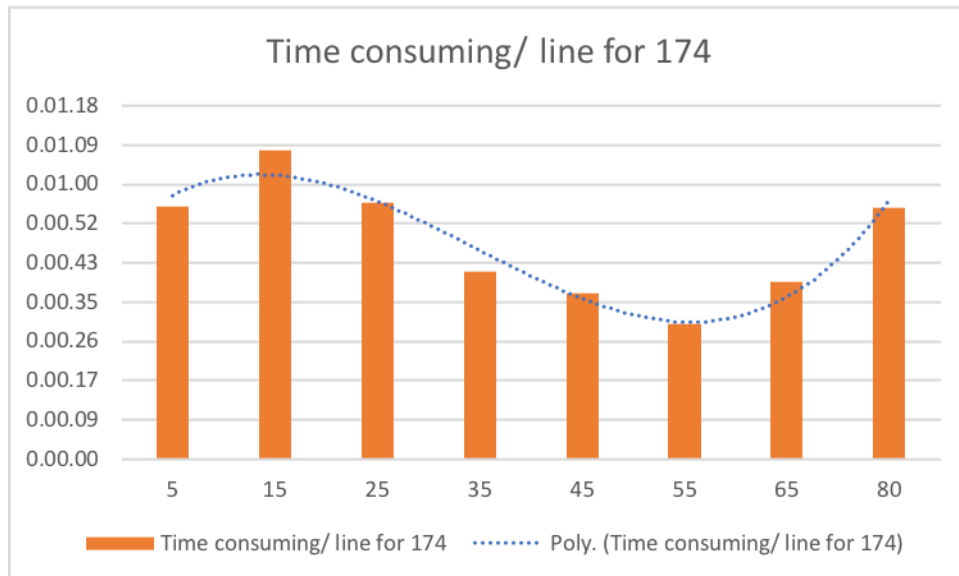


Figure 14. Picking Time/Line for the picker 174.

As Figure 14 shows, as long as the size of the picklist increases, the picking time/ line starts to increase significantly, peaked at 15 lines, and then it decreases to bottom at 55 lines (around 30 seconds/line), but thereafter it again increases dramatically.

To sum up, generally, the picking time/line decreases along with the increase of picklist size, and the optimal appears when the picklist includes 55 lines. Therefore, it is better to suggest that, if more than 1 hour before priority time, a pick route needs to include at least 25 lines but no more than 55 lines. Within 1 h for those urgent orders, there is no limitation.

As for order batching, the case company currently uses the time windows for batching orders. Each transporting service provider has a specific departure time in the case company, and orders are batched based on the shipping time and the customers. As warehouse manager mentioned, so far this batching method works quite well.

5.4 Pick Performance Measurement

Next, the performance is scrutinized and improvement proposals are suggested.

5.4.1 Statistical Analysis for Setting Evaluation Standard

The concept of elements of statistical analysis is discussed in Section 4.2.2. In this section, statistical analysis is applied to set a proper evaluation standard. Firstly, the real raw picking data of April 2018 of the case company were collected from WMS system, with the help with key stakeholders. And then, based on these raw data, critical data mining was conducted. Furthermore, all key findings from data mining were cross-checked by other data and other stakeholders, such as picking supervisor and warehouse manager. Finally, the key findings were open discussed and presented in several workshops and got confirmed from managers of the case company.

To set a proper evaluation standard for the case company, the picking time per line was selected as KPI. According to the statistical analysis of real picking data, the average picking time per line in each zone are calculated. Accordingly, the picking lines per hour in relevant zone are inferred using $3600 \text{ seconds} / (\text{picking time/line})$. Based on these information, the evaluation standard is formed, shown in Table 12.

Table 12. Evaluation Standard for each zone.

ZONE	PICKING TIME PER LINE	LINES/HOUR	INITIAL PROPOSAL		FINAL PROPOSAL
MATALA	0.01.27	41.4	50		50
AKKU	0.03.35	16.7	20		20
ATOY	0.03.16	18.4	15		15
AUTO	0.00.44	81.8	72.5		80
KORKE	0.02.12	27.3	20		25
PUTKI	0.01.17	46.8	25		45
ALUET	0.01.09	52.2	50		50

In Table 12, the initial proposal of evaluation standard comes from the key stakeholders (Data 2). Also, the final proposal comes from the statistical analysis of historical picking data. It is clear that the picking time per line varies zone by zone. In zones MATALA and AKKU, the real performance is lower than evaluation standard. Here the author recommends keeping the same as the initial proposal since another test about reducing the travel distance of zone MATALA is still in-the-process. In zone AUTO, KORKE, and PUTKI, the evaluation standard is revised from to 80 (72.5), 25 (20) and 45 (25), respectively. Zone ALUET and ATOY the standard keeps the same as initial proposal, 15 and 50, respectively.

5.4.2 Visualization

The idea of visualization is discussed in Section 4.2.3 and highlight in the conceptual framework. In this subsection, visualization is applied in warehouse operating management.

With the help of IT staff, a real-time monitoring system was developed. According to the data of WMS system, every picker's real-time performance could be shown in a table (Shown in Table 13). Thus, all pickers could know their performance timely, as well as their colleagues.

Table 13. Visualization of pickers real-time performance.

DATE	WORKER	PICKED LINES	RESTOCKING LINES	PUT-AWAY	PRODUCTIVITY
04.09.2018	111	213	0	0	213
04.09.2018	112	197	0	0	202.23
...

As discussed in CF, pick line is one of the most popular indicators for assessing picker's performance. Thus, this study chooses pick line as the KPI in measuring performance. The Table 13 illustrates, the pick performance of a picker is formed via multiplying picked lines by a coefficient of according zone. If pickers work in other tasks, such as restocking, the final performance of a picker is a sum of different activities he did.

Additionally, these historical data are also visualized by regularly reporting to stakeholders. Some simple charts and tables are introduced for visualizing data information in order to communicate with pickers smoothly and easily, such as examples in Section 5.3.

5.5 Summary of the Proposal Draft

Based on the analysis above, the initial proposal is summarized, shown in Table 14.

Table 14. Summary of Initial proposal.

	Key focus area from CS	Initial proposal
1	Longer Unproductive Travelling	<ol style="list-style-type: none"> 1. Rearrange warehouse layout, especially following addresses: M0902B, L0823B, M112, M113, K107, K112, K113, K114. 2. Re-slot fast-moving area. 7 dark color and 66 red color locations as well as all Class A items should locate in aisle G and H and follow pickfrequency based storage strategy. 3. Divide zone 12 into 3 sub-zones: A-F, G-J and K-U. Integrate two depots to one. 4. Adopt zone-picking for new sub-zones and keep the routing police as before (two-sided S-shape strategy) 5. Apply new picking rule: if more than 1 hour before priority time, a picklist needs to include at least 25 lines but no more than 55 lines. Within 1 h for those urgent orders, there is no limitation.
2	Less Efficient Performance Measurement	<ol style="list-style-type: none"> 1. Apply a new method to measure pickers performance, each zone set a specific standard (lines/hour): MATALALA: 50; AKKU: 20; ATOY: 15; AUTO: 80; KORKEA:25; PUTKI: 45; ALUET: 50. 2. Develop a real-time monitoring system based on the data of WMS system by IT staff to show the picker's real time performance 3. Install a screen on the wall to visualize pickers' real-time performance. 4. Revise evaluation standard according to performance data

As Table 14 show, it lists out key points of initial proposal, as well as some necessary steps for implementing it. Here, there are some specific instructions for the action plan. As for dividing old zone MATALA to several sub-zones, it may cause problems of allocating tasks because currently there is only 2 pickers work in zone MATALA before 10 a.m. and after 8 p.m. Thus, the author suggests this proposal works only during the busy time (from 10 a.m. to 6 p.m.) or rethinks the work schedule. In addition, for the pick-up orders and the wholesaler's orders, the picking method keeps the same as before.

Next section is about the validation of these initial proposals based on the testing in the real workplace and feedbacks from decision makers.

6 Validation of the Proposal

This section reports on the results of the validation stage and points to further developments to the initial proposal. At the end of this section, the final improvement proposal is presented. The purpose of this section is to finalize a reliable, meaningful and validated recommendation for the case company to improve order picking process.

6.1 Overview of the Validation Stage

In Section 3, longer unproductive travelling and less efficient picking performance measurement are identified as the focus area of improvement. Thereafter, Section 4 offers the existing knowledge on addressing these two selected weaknesses from literatures. In sequence, Section 5 builds the initial proposal based on previous study and Data 2.

This section validates the proposal developed in Section 5. The purpose of this step is to make sure the proposals are effective and useful for solving business challenge of the case company.

The validation process consists of three steps: firstly, test the initial proposal on a small scale in the case warehouse and collecting relevant data. Then, check the performance of new methods and analyze its performance based on relevant data. Finally, revise the weaknesses of the initial proposal and form the final proposal.

The initial proposal was tested in two rounds. The first round of testing is conducted in April of 2018. and the second round is done in May of 2018. The details of testing schedule are shown in Table 15.

Table 15. Test Schedule of Initial Proposal.

TIME	TEST CONTENT
9th. APRIL.2018	Test visualization management
18th. MAY.2018	Create fast-moving zone: "MASSA"
28th. MAY.2018	Create slow-moving zone: "K-U" and pallet picking zone: "LAVA"

29th. MAY.2018	Replace zone “ALUET” by ‘PKS’
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6.2 Findings of Data Collection 3

During Data 3 collection, the key stakeholders provides plenty of practical and meaningful comments on the validation of proposal. Table 16 shows the key points summarized from stakeholder statements.

Table 16. Summary of Data Collection 3.

	Key focus area from CS (from Data 1)	Feedback
1	Less Efficient Performance Measurement	<ol style="list-style-type: none"> 1. Need supports from IT staff and pay more attention on statistical analysis. 2. Use Finnish pallets and longer-armed picking machine to pick multiple orders; 3. There is a “data trick” in zone PUTKI. Historical data cannot reflect the fact happened in zone PUTKI.
2	Longer Unproductive Travelling	<ol style="list-style-type: none"> 1. Test proposal without changing warehouse layout on a large scale. 2. Create sub-zone “LAVA” for handling pallets. 3. Batch picking orders in zone “PKS” (ALUET) after 5 p.m.

As Table 16 presents, many useful and practical feedbacks from key stakeholders are summarized and listed. For example, one highlight comment from the warehouse managers is calling for separating the pallet pick from others by create a new group “LAVA”. According to the existing knowledge, separation of pallet pick from pieces pick is good for the pickers’ operation so as to help to increase the productivity of picking. Therefore, this suggestion is accepted and applied.

6.3 Developments to Proposal Based on Findings of Data Collection 3

The validation of initial proposal was conducted in two rounds during April and May of 2018. Accordingly, this section is split into two sub-sections.

6.3.1 Visualization Management of Validated Proposal

The first round of test includes visualization management and picking rules. It is implemented on 9th April 2018. This test is conducted in condition of unchanging other factors. The result of this test is shown in Table 17.

Table 17. Result of visualization management.

	PERIOD	TOTAL LINES	WORKING DAYS	LINES /DAY	LINES /HOUR	INCREASE
HISTORY	Year 2017	581012	254	2287.4	31.33	37.6 %
BEFORE	3rd. Apr.- 6th. Apr. 2018	10268	4	2567	35.16	22.6 %
AFTER	9th. Apr.- 27th. Apr. 2018	47214	15	3147.6	43.12	

As Table 17 shown, comparing with the historical performance, the productivity of the case warehouse (picking lines/labor hour) increases 37.6%; and compares it to the same month before testing, it increased from 35.16 lines to 43.12 lines, growing by 22.6%. Thus, this proposal is positive and effective for the case company.

However, there exist some drawbacks of this test. For example, in order to improve the picking productivity, the manager team of the case company spend much more time on doing specific work, like picking or restocking. However, these managers nearly have no time to consider the big picture of warehouse management. This may cause other problems of case warehouse in near future.

6.3.2 Reduction of Unproductive Travelling of Validated Proposal

The second round of test is implemented in MAY 2018, and it includes 3 main contents: create the fast-moving zone, the slow-moving zone and the pallet picking zone. This test was conducted in condition of without changing the original warehouse layout. Thus, it could only achieve part of benefits on proposal 2. The test result is shown in Table 18.

Table 18. Result of reduction of unproductive travelling.

	PEROD	TOTAL LINES	WORKING DAYS	LINES /DAY	LINES /HOUR	INCREASE
BEFORE	2nd. MAY - 17th.MAY, 2018	36152	12	3012.7	41.3	
AFTER	28th.MAY - 31th.MAY, 2018	13351	4	3337.8	45.7	10.8 %

From Table 18, it is clear that the result of test is also positive. Comparing to the period before test, the productivity (pick lines per hour) increases from 41.3 to 45.7, around 10% extra growth.

In addition, the picking time per line of different zones is calculated according to the real performance of 28-31 May 2018, shown as Table 19. Meanwhile, the corresponding information of April 2018 is listed out for making comparison.

Table 19. Picking Time Per Line of second round test.

28.MAY-31.MAY.2018			3.APR-30.APR.2018	
	PICK TIME/LINE	LINES/HOUR	PICK TIME/LINE	LINES/HOUR
MATALA	0.01.19	45.6	0.01.27	41.4
MASSA	0.00.44	81.8		
K-U	0.01.29	40.4		
LAVA	0.01.01	58.1		
AVE.(MATALA)	0.01.08	52.9		
AKKU	0.02.40	22.5	0.03.35	16.7
ATOY	0.03.31	17.1	0.03.16	18.4
AUTO	0.01.02	58.1	0.00.44	81.8
KORKE	0.02.12	27.3	0.02.12	27.3
PUTKI	0.01.11	50.7	0.01.17	46.8
PKS (ALUET)	0.00.57	63.2	0.01.09	52.2

From Table 19, comparing to the picking performance of April 2018, the productivity of test period also outperforms that of April. In detail, the picking time per line of zone MATALA decreases 19 seconds, dropping from 1 minute 27 seconds to 1 minute 8 seconds. Similar improvements happen in zone AKKU and ALUET, decreased 75

seconds and 11 seconds, respectively. The data of zone ATOY, KORKE and PUTKI keeps the similar level as before.

On the contrary, the picking time of zone AUTO increases significantly from 43 seconds to 1 minute 2 seconds. Through further study and analysis, the author finds that the automation system of case warehouse is partially broken on 29 May 2018. Thus, this change does not need to worry about.

6.4 Final Proposal

The final proposal is formed via merging the initial proposal and its validation stage (Data 3). The summary of the final proposal is shown in Table 20.

Table 20. Summary of improved proposal for order picking process.

	Key focus area from CS (from Data 1)	IMPROVEMENT PROPOSALS
1	Longer Unproductive Travelling	<ol style="list-style-type: none"> 1. Rearrange warehouse layout, especially following addresses: M0902B, L0823B, M112, M113, K107, K112, K113, K114. 2. Re-slot fast-moving area. 7 dark color and 66 red color locations as well as all Class A items should locate in aisle G and H and follow pickfrequency based storage strategy. 3. Divide zone 12 into 4 sub-zones: A-F, G-J, K-U and LAVA. 4. Adopt zone-picking for new sub-zones and keep the routing police as before (two-sided S-shape strategy) 5. Apply new picking rule: if more than 1 hour before priority time, a picklist needs to include at least 25 lines but no more than 55 lines. Within 1 h for those urgent orders, there is no limitation. 6. Use Finnish pallets and longer-armed picking machine to pick multiple orders.
2	Less Efficient Performance Measurement	<ol style="list-style-type: none"> 1. Apply a new method to measure pickers performance, each zone set a specific standard (lines/hour): MATALALA: 45; MASSA: 80; K-U: 40; LAVA: 50; PKS(ALUET): 60; AKKU: 20; ATOY: 15; AUTO: 80; KORKEA:25; PUTKI: 25; 2. Develop a real-time monitoring system based on the data of WMS system by IT staff to show the picker's real time performance

		<ol style="list-style-type: none"> 3. Install a screen on the wall to visualize pickers' real-time performance. 4. Regularly revise evaluation standard according to performance data
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This final proposal consists solutions for addressing selected weaknesses for improving order-picking process of the case company. In each part, specific recommendations are listed, along with some suggestions for implementation.

Next section draws a conclusion for this study and discuss further managerial implications.

7 Conclusions

In previous sections, the improvement proposal is drafted and validated in the case warehouse. This section presents the summary of this study and discusses managerial implications for next steps. In addition, evaluation of the outcomes, validity, reliability of this thesis is conducted.

7.1 Executive Summary

This paper focuses on improving the picking process of the case company. In the case company's warehouse, order-picking, similarly to other typical warehouses, is the most labor-intensive and costly activity, accounting for up to 55% of the warehouse operating cost. The biggest amount of labor is rented from a third party to save labor cost but picking productivity is still a bottleneck for warehouse operation. Thus, the purpose of this thesis is to propose improvements to the picking process of the case company.

After identifying the objective, action research was selected as the research approach for conducting this study, which involved diagnosing, planning, taking action and evaluating activities and is a cyclical process. Furthermore, three rounds of data, including qualitative and quantitative data, were collected using various methods and analyzed using content analysis, making an adequate and solid foundation in regard to research quality.

The study started from current state analysis to find out the weaknesses and strengths in the current order picking process of the case company. In this part, the current picking process and warehouse layout were analyzed and mapped, and the historical picking performance was analyzed, based on the stakeholder theme interviews and historical data (Data 1). The outcome of CSA was a list of weaknesses and strengths regarding the current order picking process and the current picking performance of the case company warehouse.

On the basis of the key findings from the current state analysis, this study moved to establish a conceptual framework using suggestions from existing knowledge and best practice. Here plenty of relevant literatures were studied and the mainly focus on placed on two selected areas: (a) picking performance measurement using visualization management, and (b) reduction of unproductive travel by re-slotting the fast-moving area, zone-picking and order batching.

The initial proposal called for introducing a visualization management for measuring pickers' performance and competitive mechanism via benchmarking. Furthermore, each zone was proposed a reference value to assess pickers performance with the help of statistical analysis. In addition, to reduce longer travel distance of zone MATA LA (12), the original zone MATA LA was suggested to be divided into 3 sub-sections: MESSA, MATA LA and K-U. And some special products are replaced to suitable locations.

In the following stage, the initial proposal was tested during April and May of 2018 and the result proved that substantial improvements in the case warehouse could be achieved. Comparing to the performance of 2017, the picking productivity increased from 31.33 lines/ (labor hour) to 43.12 lines/ (labor hour), grew around 37.6%, by application of visualization management. As for reduction of travel distance, approximately 10% extra improvements could be achieved by partially applying re-slot fast moving area and zone picking. This improvement is to a large extent due to the fact that before this study picking of zone MATA LA is traveling around the whole warehouse. According to the rough calculation, around 2-4 pickers can be saved, comparing to performance of 2017. The proposals are finally validated on the basis of Data 3.

If proposals on the storage strategy and picking rules could be fully implemented in a large scale, even stronger improvements could be achieved. This analysis needs to be done again in the following year to keep pace with development of the organization.

7.2 Managerial Implications

This project also suggests a number of actions from the management in order to help the implementation of the proposal.

First, professional training is needed before taking action. According to the study of the current state analysis, lack of proper training is one of the biggest weaknesses in the case company. Thus, managers should pay more attention to this point and be well-prepared for pickers training. Basically, there are two options: one is in-house training by elites and experienced managers, the other is outsourcing the project to the third party.

Second, to improve the accuracy and reliability, managers could collect more relevant data during the following months and check its performance before implementing it in a larger scale.

Third, as for visualization management, it could be further improved. Now the author uses excel to show the pickers performance, Later, it would be better if use some colorful charts. In addition, according to the historical data and current data, some comparison could be drawn out to help the warehouse management.

Additionally, some new working rules should be established. For example, when articles are over 25 lines, the current picking tool is not suitable. Thus, pickers need to use Finnish pallet with smalls plastic boxes to pick. The new proposal brings challenge for allocating tasks. For example, before 10 a.m., there is two pickers are working in MATAALA area, but there are 3 sub-areas in the new proposal. Therefore, Managers should make new rules for arrange working schedule, for instance, the case company could decide this new proposal is only applied during 10 a.m. -6 p.m., which could insure the whole team work smoothly and reducing effect on current picking process.

Finally, other practical ideas need to be taken into consideration, such as improving lighting. Because better lighting means that order-pickers can see better, which reduces search time when picking orders, particularly when picking pieces rather than cases, as is increasingly common. It also reduces errors in both picking and put-away, which means fewer errors in customer orders and fewer returns. In short: better service. In case warehouse, there are many addresses are at the back side of rack, where nearly no light available and increases difficulties of picking and restocking.

7.3 Thesis Evaluation

There are multiple criteria for evaluating the quality of a paper, such as rigor, validity, reliability, logic, relevance, trustworthiness, transferability, etc. Different researchers have various notions. According to Halldorsson and Aastrup (2003), typically, four criteria are applied to evaluate the quality of the study, which are construct, internal, external aspects of validity and reliability tests. Naslund (2010) hold a similar idea. While Maxwell (2012) states that validity also refers to correctness and credibility of the description, interpretation, explanation and conclusion. Thus, although there is a lack of standardized quality criteria for evaluation of research, the quality of qualitative research primarily relies on validity and reliability, along with other criteria, such as logic and relevance (Quinton & Smallbone 2006)

Validity requests that the stated evidence is valid. In other words, it means whether the author studied what he said he wound in the title and research objective, whether the

data collection is rigorous and sufficient, and whether the result is reported explicitly. The traditional validity includes: construct validity, internal validity, external validity.

In this study, validity was ensured by meeting the following requirements. At the beginning of the study, the goal of this study was established together with the case company. It was also checked and ensured at the end that the outcome of the research matches the objective and the business challenge of the case company. During the whole study, it kept its focus on the key steps to achieving this objective, meaning an objective-oriented way of working. As regards the data sources, this research adopts sufficient internal documents and plenty of theme interviews to support the study. For example, in the current stage analysis stage, the author collected the historical picking data set of the case company, which includes all transactions of picking activity of the whole year of 2017. Similarly, in building the initial proposal part, the author reviewed the whole picking data set of 04.2018. These documents are both the primary data and secondary. In addition, when mapping the current picking process, different-level pickers were interviewed from experienced to newcomers and various personal notions has been collected and studied. As for data collection, various data collecting methods were applied, such as face-to-face interviews, key stakeholder workshops, analysis of numerical data and company internal reports and document, and participant observations.

Reliability asks to check if the stated evidence is correct and the result is replicable. The accuracy of the used evidence is a key element and prerequisite of reliability of research. Using different data sources and various data collection methods could decrease bias. Furthermore, utilizing existing theory in the relevant field, choosing relatively larger number of informants and documenting data properly could also increase the reliability of research (Naslund et al. 2010). In quantitative research, reliability is mostly about consistency of the results. One important method to ensure consistency is test-re-test, for example, asking the same questions at the different points or using alternative formulations.

In this paper, reliability was ensured via implementing the following actions. First of all, the quantitative data of the case company were all raw data, without any artificial manipulation. The statistics methods applied in this study are general and based on the literature study (discussed in Section 4). All the results of statistics analysis were double-checked by the key stakeholders of the case company, and mostly, the results of analysis were kept in line with the practical experience of the front-line workers. As for the

qualitative data, different data collecting methods were used and relatively larger group of informants (over 61% of total pickers of the case company) were interviewed. The all confirmed picking process, in some way, demonstrates the accuracy of qualitative data. Furthermore, to address the weakness found in the current state analysis, a tailored and relevant theory was studied and applied. All interviews were documented by field notes, and the final proposal was based on quantitative analysis and the outcome of conceptual framework, as well as key stakeholders feedback.

In addition, *logic* and *relevance* were also considered in this study. The study first identified the business challenge together with the key stakeholder and defines the thesis objective and outcome following logicity. The proposal was built based on the results of the current picking performance and find out the weaknesses of the current picking process, and then consulted the existing knowledge to address these weaknesses. Equipped with relevant theoretical knowledge and best practice, the study focused on building the initial proposal combining the outcome of quantitative analysis, conceptual framework and key stakeholder workshop. Finally, the initial proposal was validated in the real workplace and be accepted as the final proposal. Thus, this research followed a simple but very logic way. The result matches the initial question, which means this study is also relevant.

On the other side, some limitations exist in this thesis. One weakness is that the testing time is not long enough and accordingly picking data are not sufficient. If more data are available and collected, the result will be more accurate and convictive. In this paper, the author analyzed one case warehouse and found a tailored solution for it. In future research, some more cases need to be studied. Even further, productivity comparison and benchmarking could be conducted through data collection from other cases.

7.4 Closing Words

In many typical warehouse and distribution centers, reduction of the order picking time is a constant pressure and a challenging point. How to improve the picking productivity is a challenging task for logistics and has been cited multiple times as a vital element for a logistics company. Some newest technologies and tools are invented and introduced, such as automation, robots, etc. However, the investments of capital are increasing accordingly, dramatically. Furthermore, in today's business, customers' needs and more and more personalization further increase the difficulty of operations in a warehouse.

This thesis is conducted under limited capital investment and provides a tailored solution for the business challenge of the case company, along with positive results. The study is supported by most of pickers and the warehouse managers in the case company. Most resources, including improving ideas and original data, also came from the real workplace, as well as plenty of literatures. This thesis starts from the workplace of the case company and serves for it.

Finally, the validated proposal not only provides contribution to the picking process itself, but it can also have a significant effect on the whole warehouse management, such as item profiling, lead time and so on. Managers have more granular knowledge for their warehouse and they could even forecast the amount of work and labor cost before several months. All these analysis and solutions give contribution to improve the whole warehouse performance.

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Appendix 1 Visualization of DATA 1 Collection

Order	Who	Position	When	Duration	What	Language	Record
1	Informant 1	Manager of warehouse	23.11.2017	30 mins	Business Challenges: 1. Picking process & efficiency; 2. Shelving efficiency and accuracy; 3. Shipping accuracy.	Finnish	Field note
2	Informant 1	Manager of warehouse	19.01.2018	1 h	1. Decide the Master thesis topic; 2. Explain current picking process and challenges existed; 3. Give Picking Data of the whole year of 2017	Finnish	Field note
3	Informant 1	Manager of warehouse	23.02.2018	2 h	1. Pre-Check the analysis of Picking data and give feedback; 2. Discuss the layout and Pickers' current efficiency measurement	Finnish	Field note
4	Informant 1	Manager of warehouse	01.03.2018	1 h 15 min	1. The 2 nd time Check the picking Data analysis and give feedback. 2. Mapping Current Picking process	Finnish	Field note
5	Informant 3	5+ y Picker	01.03.2018	1 h	Mapping Current Picking process	English	Field note
6	Informant 4	5+ y Picker	01.03.2018	30 mins	Mapping Current Picking process	Finnish	Field note
7	Informant 5	1-3 y Picker	01.03.2018	50 mins	Mapping Current Picking process 2. +/-	English	Field note
8	Informant 6	1-3 y Picker	08.03.2018	1 h 11 mins	Mapping Current Picking process	English	Field note
9	Informant 7	0-6 m Picker	08.03.2018	28 mins	Mapping Current Picking process	Finnish	Field note
10	Informant 8	0-6 m Picker	08.03.2018	16 mins	Mapping Current Picking process	English	Field note
11	Informant 2	Manager of Picking & Shipping	08.03.2018	1 h 20mins	1. Mapping Current Picking process; 2. Picking efficiency	English	Field note
12	Informant 2	Manager of Picking & Shipping	15.03.2018	42 mins	1. Check Picking flowchart 2. +/-	English & Finnish	Field note
13	Informant 8	0-6 m picker	15.03.2018	30 mins	1. Check Picking flowchart 2. +/-	English	Field note
14	Informant 9	3~4 y picker	15.03.2018	30 mins	1. Check Picking flowchart 2. +/-	English	Field note
15	Informant 7	0-6 m picker	15.03.2018	10 mins	1. Check Picking flowchart 2. +/-	Finnish	Field note
16	Informant 6	1~3 y picker	15.03.2018	24 mins	1. Check Picking flowchart 2. +/-	English	Field note
17	Informant 1	Manager of warehouse	22.03.2018	2 h	1. check picking flowchart 2. +/- 3. Data analysis & feedback 4. Efficiency	Finnish	Filed note
18	Informant 3	5+ y Picker	22.03.2018	10 mins	1. Check Picking flowchart 2. +/-	English	Field note
19	Informant 10	5+ y Picker	22.03.2018	20 mins	1. Check Picking flowchart 2. +/-	Finnish	Field note
20	Informant 11	5+ y Picker	22.03.2018	20 mins	1. Check Picking flowchart 2. +/-	Finnish	Field note
21	Informant 5	1-3 y Picker	29.03.2018	40 mins	1. Check Picking flowchart 2. +/-	English	Field note
22	Informant 1	Manager of warehouse	29.03.2018	1 h	1. Check the summary of CSA and decide the FOCUS of this thesis. 2. Heat map & Picking efficiency	Finnish	Field note

Appendix 2 Visualization of DATA 2 Collection

Order	Who	Position	When	Duration	What	Language	Record
1	Informant 12	Picker	19.04.2018	10 mins	what need to be trained for new comers in case co. (Picking process& how works)	Finnish	Field note
2	Informant 13	1-3 y picker	19.04.2018	20 mins	what need to be trained for new comers in case co.(choose resource, 3 steps to be best	English	Field note
3	Informant 2	14+ y Manager	19.04.2018	30 mins	What need to be trained? 1. Knowledge of products; eg.what looks like? unit of measument? light or heavier? 2. Address related issues, eg. layout; 3. Packing process, eg, brake discs, put plastic on	English	Field note
4	Informant 14	1-6 m New picker	19.04.2018	12 mins	what need to be trained? 1. how to use PDA; 2. how the warehouse organized/designed? 3. supervisor or tutor to check & consult for first two weeks	Finnish	Field note
6	Informant 2	14+ y Manager	26.04.2018	30 mins	1. Check the initial proposal; 2. Make a Plan for valitating proposals.	English	Field note
7	Informant 5	1-3 y Picker	26.04.2018	20 mins	Check the initial proposal (max. 150 lines)	English	Field note
8	Informant 1	Manager of warehouse	03.05.2018	2 h	1. Check the initial proposal: 2. Discuss efficiency and challenges of new method; 3. Make a plan for validate proposals.	Finnish	Field note
9	Informant 1	Manager of warehouse	04.05.2018	1 h	1. Check the initial proposal: 2. Discuss efficiency and challenges of new method; 3. Make a plan for validate proposals.	Finnish	Field note

Appendix 3 Visualization of DATA 3 Collection

Order	Who	Position	When	Duration	What	Language	Record
1	Informant 2	14+ y Manager	17.05.2018	20 mins	Validation of proposal The first part test feedback Time window for order batching	English	Field note
2	Informant 5	1-3 y Picker	17.05.2018	20 mins	Validation of proposal	English	Field note
3	Informant 1	Manager of warehouse	29.05.2018	30 mins	Validation of proposal	Finnish	Field note
4	Informant 1	Manager of warehouse	05.06.2018	20 mins	Feedback of testing 1. "Data trick" in zone "PUTKI" 2. Limitation of test 3. Action plan	Finnish	Email & Phone call
5	Informant 1	Manager of warehouse	18.06.2018	30 mins	Implementation of improvement proposals	Finnish	Email
6	Informant 1	Manager of warehouse	10.08.2018	30 mins	Closing discussion 1. Evaluation of the study 2. Future study direction	Finnish	Field note